International Journal of Aquatic Research and Education

Volume 2 | Number 1 Article 8

2-1-2008

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Recommended Citation
Hunsucker, John and Davison, Scott (2008) "How Lifeguards Overlook a Victim: Vision and Signal Detection," *International Journal of Aquatic Research and Education*: Vol. 2: No. 1, Article 8.
DOI: https://doi.org/10.25035/ijare.02.01.08
Available at: https://scholarworks.bgsu.edu/ijare/vol2/iss1/8

INVITED REVIEW

International Journal of Aquatic Research and Education, 2008, 1, 59-74

How Lifeguards Overlook Victims: Vision and Signal Detection

John Hunsucker and Scott Davison

Each one of the over 3,000 drownings that occur every year in the United States is a tragedy (Kochanek, Murphy, Anderson, & Scott, 2004), but when a drowning occurs during the time a lifeguard is on duty, additional questions need to be asked. Over the years, we, as part of our responsibilities as officers of the National Aquatics Safety Company (NASCO), have investigated numerous incidents of drowning that should have been obvious to the lifeguards on duty. Now the most pressing questions become, "What went wrong? Why didn't the guard see and recognize the victim in time to prevent the drowning?"

NASCO has taken a different approach to researching these questions than is usual in our industry. Many of the practices and procedures in lifeguarding were not developed using commonly accepted scientific or engineering principles but evolved from individual lifeguard experiences. This has been true from the days of Commodore Longfellow in 1914, when he and the American Red Cross founded the Red Cross water-safety education program and the Red Cross Life Saving Corps (International Swimming Hall of Fame, n.d.). At the beginning of the century, the national drowning rate was 10.4 per 100,000 (International Swimming Hall of Fame, n.d.). The lifeguarding practices and procedures that have been developed over the last century plus the swimming programs that have taught hundreds of millions of Americans to swim have reduced that drowning rate significantly to 1.2 per 100,000 in 2002 (Kochanek et al., 2004).

This type of "experiential" approach has saved uncounted lives, but the environment in which lifeguards operate has changed. For most of the 20th century, most lifeguards worked at waterfronts or small flat-water pools serving a few thousand people a season. This started to change in the 1980s, and now a large number of lifeguards work in water parks where they might be responsible for thousands of guests in a single day and litigation awaits every incident. Lifeguarding practices and procedures need to be based on the same principles that are used by other industries in which an individual can affect public safety—examples being commercial airline pilots, nuclear-power-plant operators, and long-haul truck drivers. This does not mean that aquatic facilities should be considered common carriers or hazardous industries. They are very different from those types of industry, although some legislators and jurists mistakenly persist in trying to make the connection. Nonetheless, some of the extensive research and development that has been applied to workers in those industries needs to be applied to lifeguarding. In fact, the 2002 World Congress on Drowning in Amsterdam recommended, as item number 6 of its 12 recommendations, that

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Rescue techniques must be investigated.

> Most of the current rescue techniques have evolved by trial and error, with little scientific investigation. Rescue organizations . . . must be encouraged to evaluate the self-rescue and rescue techniques in their training programs in accordance with current scientific data on the effectiveness and efficiency. Based on the data, the best rescue techniques must be selected for education and training programs. (World Congress on Drowning, n.d.)

Our backgrounds at NASCO include extensive experience in engineering, aquatic safety, risk management, and emergency services plus graduate degrees in engineering and mathematics. This article looks at several aspects of how lifeguards see and recognize a victim, including vision and signal detection. Even though all lifeguarding agencies teach some form of how to see and recognize a drowning victim, there is much disagreement on the mechanics of doing so. In fact, the American Red Cross has stated that it would not accept one common lifeguarding practice by saying "there was no basis, background, or references to research" (American Red Cross, n.d.).

Our hope is that this article will provide a methodology to resolve some of these disagreements. It is essential that lifeguards be taught how to look and what to recognize. These are, perhaps, the most important of the basic issues in scanning. Without having solved the issues of seeing and recognizing a victim, modifying such factors as environment (heat, hydration, glare, etc.), stress, and mental state, although important, will not be effective. Of course, the lifeguard's physical well-being still needs to be considered. The point is that these other factors will not have a substantial effect on a guard's effectiveness unless the issues of seeing and recognizing victims are resolved first.

It should be noted that we do not contend that the concepts presented in this article are the only way to deal with the issues cited. Experience has shown that this approach has been successful and supportable based on commonly accepted scientific and engineering principles.

Background and Definitions

Two of the theoretical areas that bear on how a lifeguard sees and recognizes a drowning are those of signal-detection theory and vision.

Signal-Detection Basics

Identifying a Signal. In the lifeguard's case identifying a signal refers to seeing a victim or an event that requires lifeguard intervention. If the signal is seen, this is called a hit, and if not seen, a miss. For our purposes, efficiency is defined as the ratio of hits to signals. As an example, if everything that should be seen were seen, this would be 100% efficient. Because a miss often leads to a drowning, anything less than 100% efficiency is unacceptable.

Structuring the Search Space. One established principle in signal-detection theory is that if the search space is relatively unstructured the search tends to become random and nonexhaustive. If the space is organized, for example like a

DOI: https://doi.org/10.25035/ijare.02.01.08

checkerboard, people tend to search from top to bottom and left to right. If the visual space is not organized, like in a swimming pool, locations will likely be missed (American Red Cross, n.d.). Put another way, unless lifeguards are taught a pattern to use, the probability that they will miss significant portions of their area is very high. Although other factors bear on the ability to detect a signal, the structure of the search is crucial to success and is, for the most part, more important than the other factors. For this reason, this article will go over a number of effective and ineffective scanning patterns.

Making a Signal Conspicuous. Another well-know principle of signal-detection theory is that the more conspicuous a signal, the more likely a hit will occur. Because a drowning victim's signals cannot necessarily be made more conspicuous, the other option is to increase the sensitivity of the lifeguard to recognizing the signal (American Red Cross, n.d.). This can be done by training the lifeguard in what to look for in a drowning victim. Although it is true that some victims exhibit major symptoms of distress, such as those who suddenly find themselves in deep water or in a current, it is also true that many victims do not necessarily exhibit these symptoms. Some victims drown very quietly. Details of the symptoms of drowning can be found in the section on victims and victim recognition.

Signal Frequency. The last principle of signal-detection theory we cover in this article has to do with the frequency of the signal. It is well established that finding signals with a low frequency of occurrence is much more difficult than finding signals that occur with a high frequency. Put another way, if the signal is relatively rare, the percent effectiveness is much lower than with a commonly occurring signal (Grandjean, 1990). If lifeguards do not expect to find something, the probability that they will miss the signal is very high. Signal frequency should deal with ways to increase both the frequency of the signal and the sensitivity of the lifeguard to the signal by using simulations and drills.

Vision Basics

Vision is based on how the eye and brain collect and interpret light rays reflected off an object. The basic anatomy of the eye determines to a large degree the structure of a signal-detection task. At the back of the eye where the light rays are focused are two different types of receptor cells, rods and cones. The cones are very dense at the immediate rear of the eye, and the rods are dense along the sides of the back of the eye. The density of the cones declines along the back until there are mostly rods along the sides (see Figure 1; Grandjean, 1990). Cones are used in focusing. Light rays contacting the cones are seen clearly. The rods, on the other hand, are good mostly for detecting major motion and light.

This structure determines the three separate and distinct fields of vision. The three fields are the inner field, the middle field, and the outer field (see Figure 2; Grandjean, 1990). The inner field is a cone of sight (not to be confused with the eye's receptor cells called cones) with an angle of about 1°. An object must be located in this field for one to be able to discriminate it. That light in this field will then fall on the cone cells clustered at the very back of the eye. The eye will then focus on that object. To make the final determination of whether a person is drowning, lifeguards must get their view of the person in the inner field.

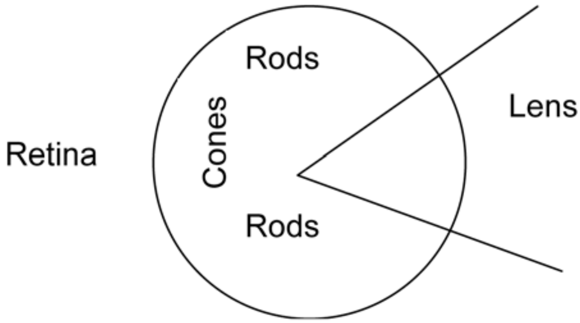
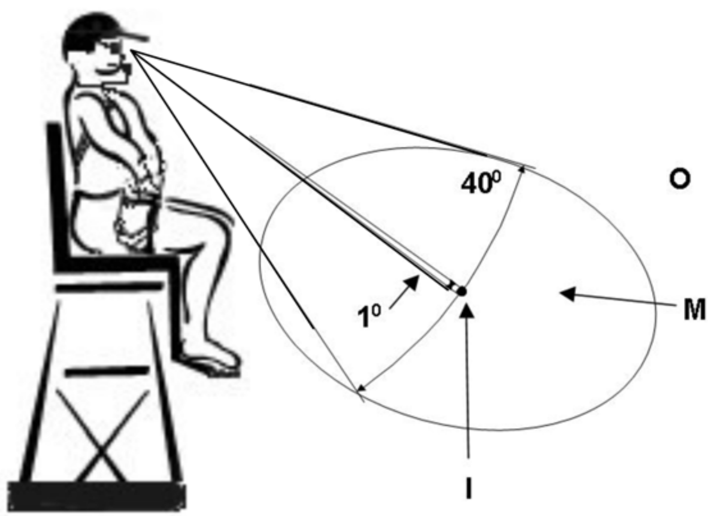


Figure 1 — Schematic of the eye.



Field of View – That Part of the Observable World That You Are Able To See at Any Given Moment

I=Inner Field – Angle of View of 1° Sharp Vision, Excellent Color and Movement Perception

M=Middle Field – Angle of View from 1° to 40° Blurry Vision, Ability to Perceive Color and Movement Well

O=Outer Field – Everything Else You See Minimal Vision, Minimal Color Perception, Ability to See Some Movement

Figure 2 — The fields of view.

DOI: https://doi.org/10.25035/ijare.02.01.08

The middle field is a cone of sight with an angle of about 40°. The light in this field falls primarily on the rod cells. Although objects in this field are not seen clearly, strong contrast and movements are noticed. To locate victims, a lifeguard must cover their entire zone with the middle field. Then, once a weak signal is noticed, the lifeguard can bring the image into the inner field to focus and to see if the person is really in distress.

The outer field is everything else that is visible. About the only thing noticeable in this field is major motion. One of the common ways to miss a signal is to think that the outer field will detect victims. The only way this will be successful is if the victim is showing major signs of distress with a lot of motion. Quiet drownings and victims on the bottom will normally not be seen if they are only in the outer field.

As an experiment to locate the boundary between the middle and the outer fields, hold your hands straight out horizontally at your sides with a certain number of fingers pointing straight up. While looking straight ahead, bring your hands together if front of you until you can count the fingers and stop. Though not exact, this will give a rough idea of the size of the vision cone that must be used to cover the entire zone.

Another ergonomic principle that is needed for this discussion is the line of sight as determined by the normal downward angle of neck/head posture. Most authors in the field consider 15° a normal neck/head posture (Grandjean, 1990). This in turn determines the normal line of sight of 15°. Therefore a line of sight of 15° will be assumed throughout the rest of this article (Sanders & McCormick, 1993). A 15° downward angle leads to a line-of-sight distance denoted by F in Figure 3. Using a 40° middle field, with half above and half below the line of sight, the boundary of the middle field is denoted by M in Figure 3. This can be found by taking a 20° declination off the line of sight. Note that the effective upper boundary of the middle field is at the horizon (see Figure 3), because 15° down plus 20° up

height of guard's head above water (ft)	M (ft)	F (ft)	Full Zone(ft^2)
6	8.6	22.4	2,513
8	11.4	29.9	2,513

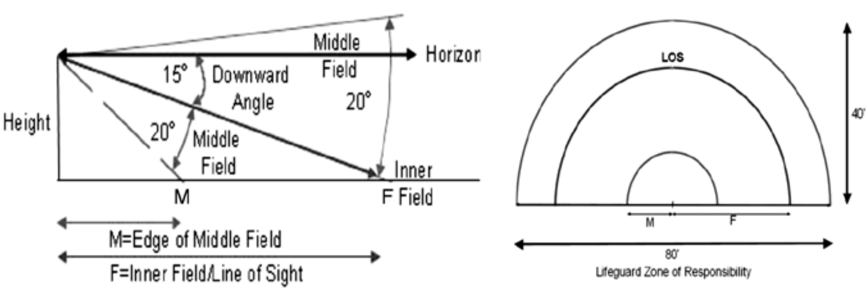


Figure 3 — Downward-angle schematic.

goes above the horizon. Based on typical lifeguard stands, we only assume that the lifeguard's eye is 6–8 ft (1.8–2.4 m) above the water's surface.

It is also important to remember that just because an area is within the inner or middle field of vision it does not mean that the lifeguard can see enough detail to recognize a drowning. This is a function of visual acuity, defined as "the amount of fine detail that can be resolved" (Wickins, Gordon, & Liu, 1998, p. 87). If a drowning victim is so far away that the lifeguard cannot receive a signal, signal recognition is not possible. The distances that determine a lifeguard's zone of responsibility should not exceed the lifeguard's ability to see and recognize the characteristics of a drowning victim as described in Table 1. For the purpose of this article, we have used a typical lifeguard zone of responsibility: a semicircle with a 40-ft (12-m) radius (see Figure 3).

Lifeguards can make several basic mistakes when they scan. One common mistake is to not cover the entire zone with the middle field of vision by using an inappropriate scanning pattern. Some of the scanning patterns shown in the following section will show how locations within a zone of responsibility can be missed. Another common mistake is to scan too quickly. The head must have a macro motion that is slow enough to allow the eye the time necessary to gather enough information about a location to identify a signal. A sweep that is too quick will not gather enough information to make that determination.

Scans

These scans have been described in the NASCO *Lifeguard Manual*. A copy of this manual can be found at www.nascoaquatics.com. The mathematics associated with these scans also can be found at this Web site.

The Partial-Arc Scan. A partial-arc scan is defined, for the purpose of this article, as a scan that goes from 45° directly to the left of the guard to 45° to the right with a 15° down angle following a circular arc. This is a common scanning pattern in lifeguarding. Figure 4 shows the areas it covers and misses. Here we assume that the lifeguard's zone of responsibility is a semicircle approximately 40 ft in radius, because this will cover a bit more than half of a 25-yd-wide pool. This results in a zone $Z = 2{,}513$ ft^2 (231 m^2). The table in Figure 4 shows the results. In this and the following scans, the term *effective* is redefined to represent the percent of the

Table 1 Recognizing Drowning Victims

Victims on or near the surface	Victims on or near the bottom
Facial expression	Unexplained color variation in pool
Irregular motion including the absence of motion	Elevated chest and drooping head
Loss of body position	Lack of motion
A head-back, nose-up posture	Bubbles
No leg kick	

Note. Victims might exhibit some or none of the above characteristics. Guard training is essential for better recognition of drowning victims. Detailed descriptions of these drowning characteristics can be found in the NASCO *Lifeguard Manual* at www.nascoaquatics.com

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DOI: https://doi.org/10.25035/ijare.02.01.08

height of guard's head above wate (ft)	Downlook Angle	L=Lower Middle Field(ft)	F=Line of Sight (ft)	U=Upper Middle Field(ft)	Full Zone(ft^2)	Area Covered(ft^2)	Area Missed(ft^2)	% Effective
6	15º	8.6	22.4	Horizon	2,513	1,199	1,314	47.7%
8	15º	11.4	29.9	Horizon	2,513	1,155	1,358	46.0%

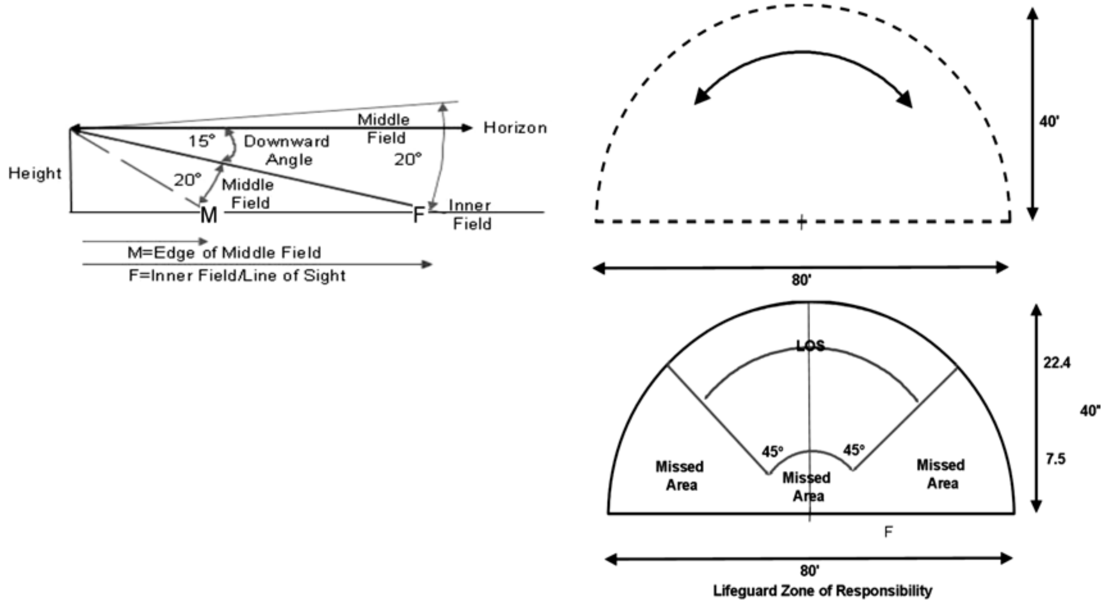


Figure 4 — The partial-arc scan.

zone that is swept by the middle field in one scanning cycle. The result of this calculation yields a significant insight into how guards can miss a victim if they use this scanning pattern. A partial-arc scan will miss over half of a lifeguard's zone of responsibility.

The Full-Arc Scan. A full-arc scan is defined, for the purpose of this article, as a scan that completes the 180° about the arc described by the 15° down angle. This is, unfortunately, also a scanning pattern used by some lifeguards. Figure 5 shows the areas covered and missed. The lifeguard's zone of responsibility is a semicircle approximately 40 ft in radius, which will cover a bit more than half of a 25-yd-wide pool. This results in a zone $Z = 2{,}513$ ft^2 (231 m^2). The table in Figure 5 shows the results. The term *effective* is redefined to represent the percent of the zone that is swept by the middle field in one scanning cycle. The result of this calculation shows that the lifeguard will miss an area right in front of the guard stand. Full-arc scans will miss 5–8% of the lifeguard's zone of responsibility.

The Full-Arc Scan With Pronounced Downward Head Sweep. This is the same scan as the full arc, but it is finished with a pronounced downward head sweep along the wall at the guard's feet. The downward sweep goes from the corner at the end of the arc along the bottom of the arc just in front of the guard to the opposite corner. It is assumed that the direct line of sight of the guard follows a path 2 ft (0.6 m) out in the water from the deck. Figure 6 shows the scan. This scan covers most of the zone of responsibility but still leaves an error of 1–1.4%. See the table in Figure 6. For the guard to miss the victim, the victim would have to be exactly centered in about a 5–6 ft^2 area about 7 ft (2 m) in front of the guard.

The Full-Arc Swing Scan With Pronounced Downward Head Sweep and a "T Bump." This is the same as the previous scan except that guards stop the downward head sweep when they are looking straight down in front of their feet and bump their line of sight straight out perpendicular to the wall of the pool, ending with a side-to-side look. The "T bump" needs to go only 8–10 ft (2.4–3 m) out. This scan is 100% effective. Figure 7 shows the path of the scan.

The Parallel-Lines Scan With a Pronounced Downward Head Sweep. This scan, if done right, is 100% effective. The scan consists of parallel-line scans followed by a pronounced downward head sweep (see Figure 8). Starting at one corner with a 15° downward look, a line is made to the other corner. Then the head is shifted down a bit and other line is swung back to the other side. These parallel lines are continued until the finish, which is a pronounced downward swing along the deck. Assuming equal spacing, a minimum of three lines and a downward head swing gives 100% effectiveness along with a huge overlap of the middle fields. Three lines with a downward head swing also help make the scan systematic because it always starts and ends at the same side. In this and the following, *coverage* refers to the amount of overlap scanned during the scan cycle. This scan provides 290% coverage and is 100% effective (see table in Figure 8).

The In-and-Out Spoke Scan With Pronounced Downward Head Sweep. This scan is also 100% effective if done correctly. Basically, it is a series of spokes starting at the lifeguard's feet and going to the outer perimeter of the zone (see Figure 9). It should finish with a pronounced downward sweep. Assuming that one of the spokes

height of guard's head above water (ft)	Downlook Angle	M (ft)	F (ft)	U=Upper Middle Field(ft)	Full Zone(ft ^{2})	Area Covered(ft ^{2})	Area Missed(ft ^{2})	% Effective
6	15º	8.6	22.4	Horizon	2,513	2,397	116	95.4%
8	15º	11.4	29.9	Horizon	2,513	2,309	204	91.9%

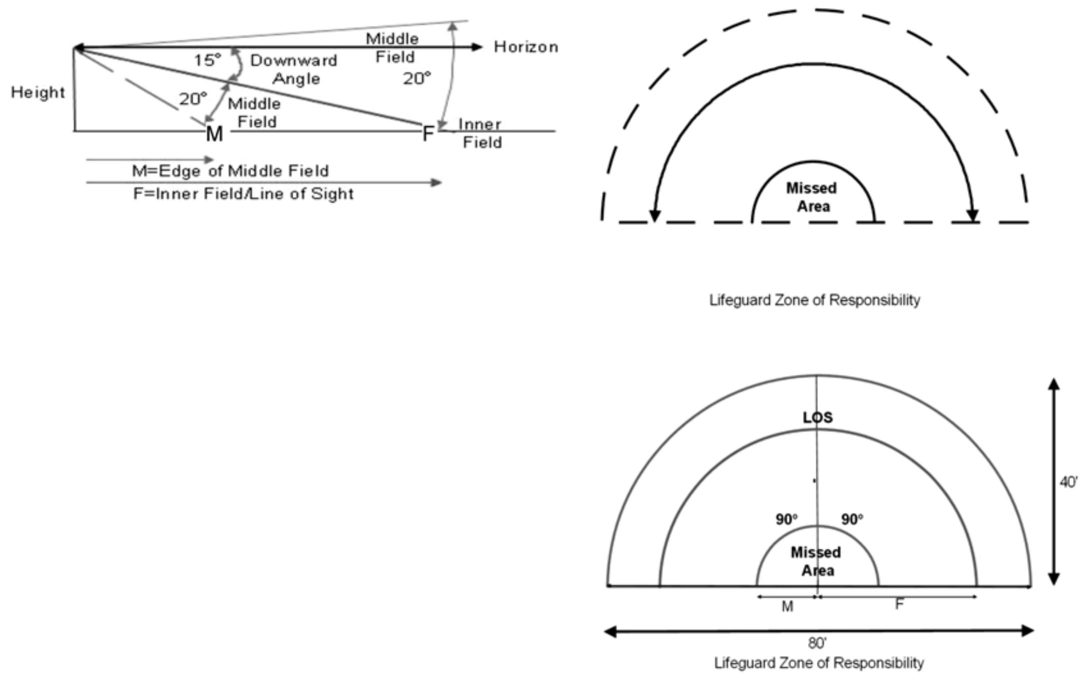


Figure 5 — The full-arc scan.

height of guard's head above water (ft)	Downlook Angle	M (ft)	F (ft)	U=Upper Middle Field(ft)	Full Zone(ft^2)	Area Covered(ft^2)	Area Missed(ft^2)	% Effective
6	15º	8.6	22.4	Horizon	2,513	2,488	25	99.0%
8	15º	11.4	29.9	Horizon	2,513	2,479	34	98.6%

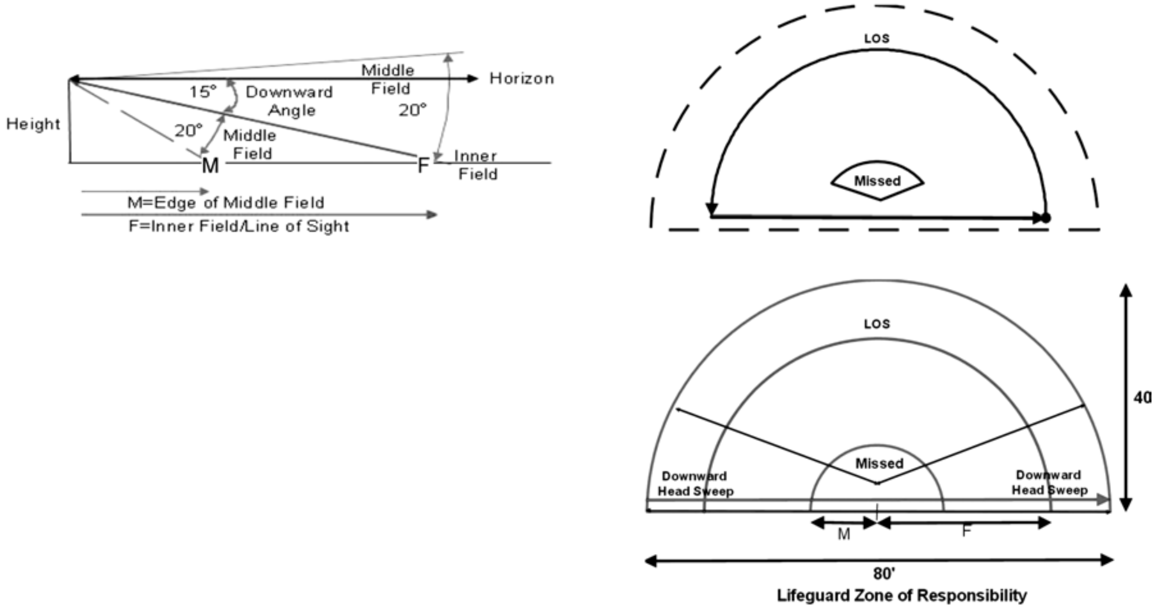


Figure 6 — Full-arc scan with a pronounced downward head sweep.

height of guard's head above water (ft)	Downlook Angle	M (ft)	F (ft)	U=Upper Middle Field(ft)	Full Zone(ft ^{2})	Area Covered(ft ^{2})	Area Missed(ft ^{2})	% Effective
6	15º	8.6	22.4	Horizon	2,513	2,513	0	100.0%
8	15º	11.4	29.9	Horizon	2,513	2,513	0	100.0%

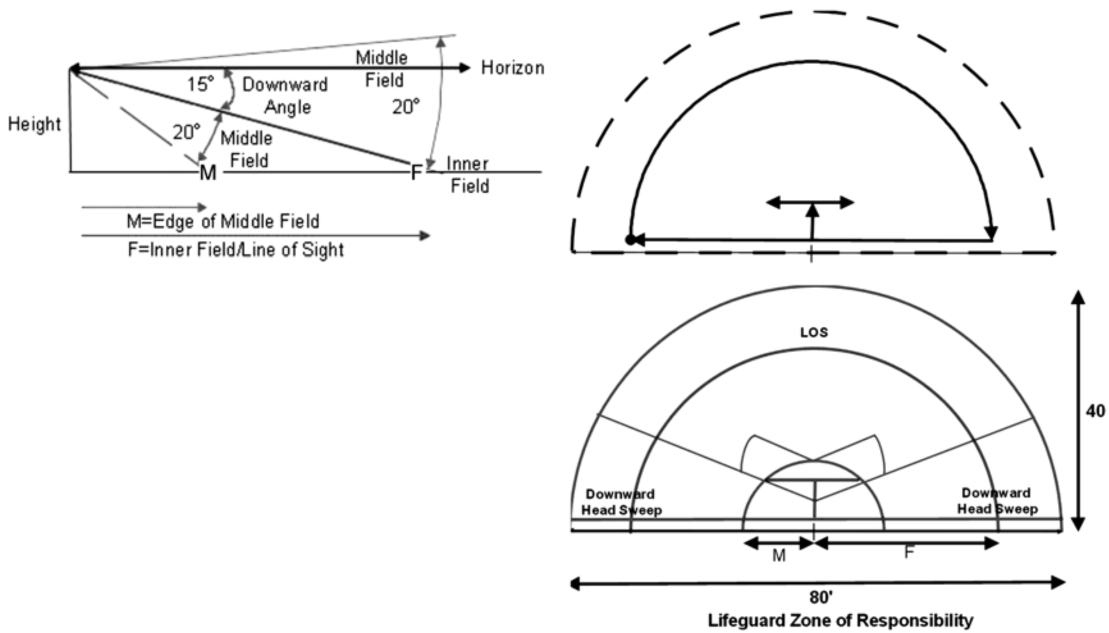
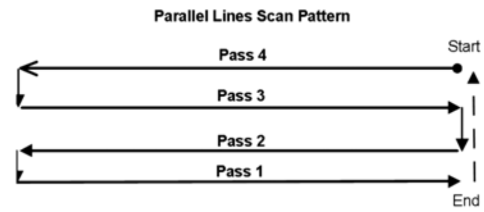


Figure 7 — Full-arc scan with a pronounced downward head sweep and a "T bump."

height of guard's head above water (ft)	Line	Downlook Angle	F=Line of Sight (ft)	% Covered	Totals
6	4	15.0º	22.4	92.1	Effective
6	3	22.4º	21.8	95.1	100%
6	2	38.7º	7.5	67.1	Coverage
6	1	71.6º	2.0	35.7	290%



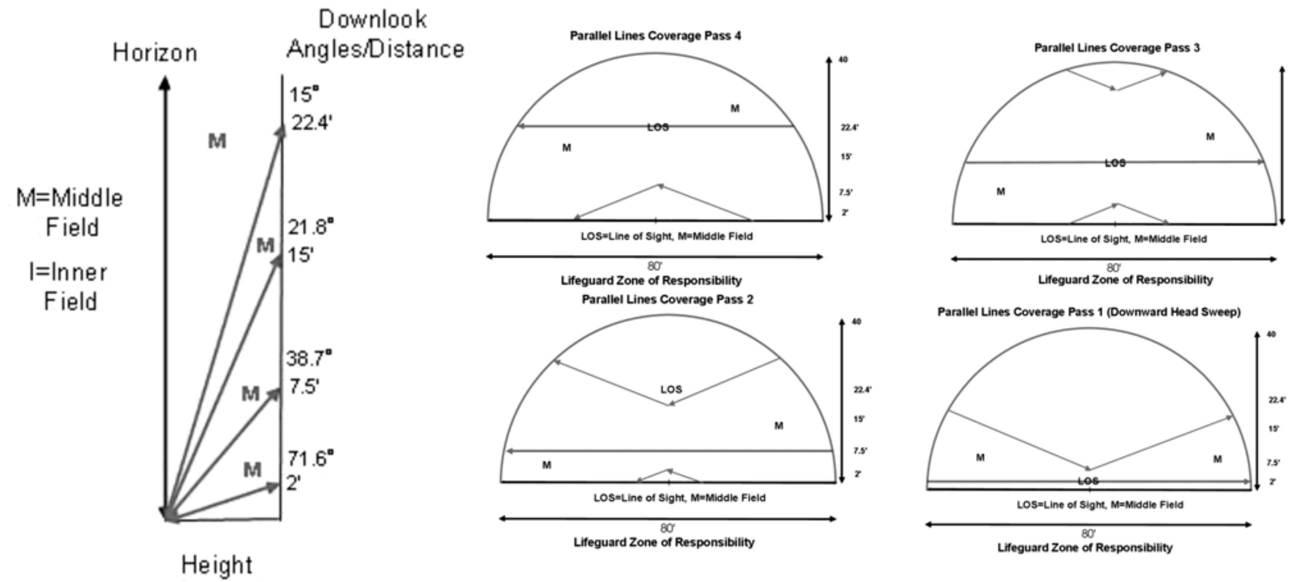


Figure 8 — Parallel-lines scan with a pronounced downward head sweep.

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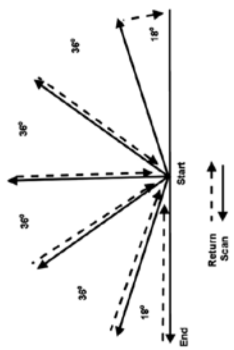
DOI: https://doi.org/10.25035/ijare.02.01.08

height of guard's head above water (ft)	Line	Lower Angle	Line Of Sight Angle	Upper Angle	Totals
6	1	Deck	18º	38º	Effective 100%
6	2	34º	54º	74º	
6	3	70º	90º	110º	
6	4	106º	126º	146º	Coverage
6	5	142º	162º	Deck	
6	6	Deck	Deck	Deck	



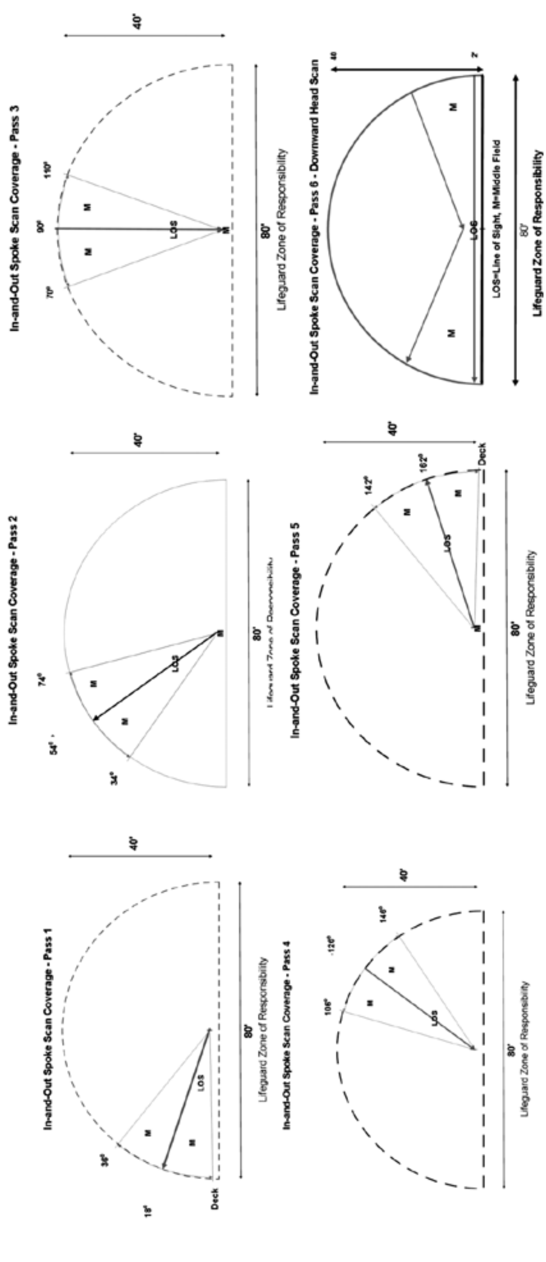


Figure 9 — In-and-out spoke scan with pronounced downward head sweep.

is going to be straight out from the feet perpendicular to the deck, an odd number of spokes is required. Five spokes is the minimum that is required to give complete coverage. This assumes the first spoke is a bit close to the deck, the second about halfway to perpendicular, the third straight out, the fourth about halfway on the other side, and the fifth a bit closer to the deck. The finish is a pronounced downward sweep of the head. This scan can be 100% effective with 132% coverage.

During the Scan

Victims and Victim Recognition. A basic principle in physics, Archimedes's law, implies that a victim will be either on or near the surface of a pool of water or on the bottom of a pool of water. Although some victims might be in transition from one place to the other, this transition is usually relatively rapid unless the victim is capable of finding some means to support him- or herself in the water. For this reason drowning victims have been classified into two groups, surface victims and bottom victims. The following general characteristics for these two groups of drowning victims have been determined by watching hundreds of rescues and from talking to lifeguards after rescues about what keyed them to the fact that the person was in distress. Please note that victims do not all drown in the same way or in the same place. That means that there will always be victims who present characteristics not listed in Table 1. To this end, lifeguards should always be taught, "If you don't know, go." A false alarm is always preferable to a miss.

These classifications are presented in summary form in Table 1. For the most part, the characteristics are presented with the most frequently seen characteristics occurring earlier in the list.

Signal Frequency. As stated earlier in this article, signal frequency (in this case an event requiring lifeguard intervention) has to occur often enough to ensure that the guard will be "primed" to recognize it. To be effective lifeguards have to have seen enough real drownings or simulated drownings to be ready to recognize the signal. Because surface victims are more conspicuous than bottom victims, this training strategy can stress (though not be limited to) finding something on the bottom.

Unsuccessful strategies have included using a brightly colored object, such as the red-ball drill, or an actual swimmer to simulate a victim. In the red-ball drill, a red ball is thrown in the water and the lifeguard has a prescribed number of seconds to locate it. Because the visual part of the brain is programmed to see bright colors as a primary stimulus (Grandjean, 1990), the red-ball drill teaches the guard to look for red, not for victims. Live swimmers have a very difficult time being realistic enough to act the part of a drowning victim. Some of the major problems include the absence of a realistic facial expression, the fact that they usually are kicking vigorously to avoid really drowning, and that a head-back, nose-up posture causes water to run up their nose.

A more effective strategy is using a mannequin or silhouette to simulate a victim in the water. The problem with using a mannequin is that it is difficult to sneak it past the guards. In fact, if the guards are so unaware that you can get a mannequin or silhouette into the water without them seeing it, you might have discovered a basic scanning and recognition problem right there. Bottom silhouettes are, in our opinion, more effective because they are easier to hide from the guards. The silhouettes should be placed in the pools frequently enough to allow the guards enough successes to keep them sharp. Another advantage of using the silhouettes is that when a guard rescues one and comes to the surface, it does not look like a victim to the guests. Remember that guests come to a facility to relax and enjoy themselves, not to be disturbed or frightened by simulated drowning emergencies.

Another strategy is to use tokens made for the drill. These tokens should be relatively dark in hue. It should be stressed again that using bright colors trains the guard to look for colors, not victims. A certain number of these tokens can be placed in the pools on a regular basis. It follows from current research that if the lifeguards know they are there and that they can be redeemed for rewards, such as drinks or food, they will be motivated to train themselves to look carefully over their areas (Wickins et al., 1998). Peer recognition resulting from posting successful guards' names will also help motivate them.

Guards in every area of a facility or water park should be given the opportunity to find something. If guards fall into the mindset of thinking that they will never see anything, when a real drowning comes along their chance of successfully seeing and recognizing it will have been degraded because of poor signal frequency.

Time and Vigilance. One final result needs to be mentioned from signal-detection theory. Almost all the human-factors studies that have been done on operators such as nuclear-plant operators, airline pilots, and even truck drivers have shown that vigilance decreases exponentially after 30 min of concentration on the same task (Hunsucker & Chen, 1994). This means that after 30 min in a position, a lifeguard's performance decreases rapidly. As a recommendation, 45 min in a position seems to be a maximum time for any lifeguard.

Conclusions

If you wish to reduce the chance of a lifeguard missing a victim, you need to teach the guard how to be successful at seeing and recognizing a victim. The lifeguard needs to learn how to look, what to look for, and then have those skills reinforced by achieving successes at seeing and recognition using a simulation device or exercise. These basic skills have to be learned first and foremost. Only after they are part of lifeguards' ability to monitor their zone of responsibility should additional attention be given to other areas affecting vigilance degeneration.

This article has concentrated on the application of geometry and visual physiology to the job of the lifeguard and thus to how the two lifeguarding skills of scanning and signal recognition can be improved. There are at least two subject areas where research can improve lifeguarding effectiveness.

The first area is to continue the application of physics and visual physiology to the field of lifeguarding by investigating such issues as the height of the lifeguard chair, the use of polarized lenses, the required visual acuity of a lifeguard, and the impact of zone size on lifeguard effectiveness. The second area deals with psychophysiology. The direction here might center on subjects such as the required mental state, factors that affect this state, and strategies to both create and maintain the necessary level of vigilance.

Although these other issues should also be investigated, we feel that this article does promote the application of basic scientific and engineering principles to lifeguarding. The application of strong solid research and scientific inquiry into the lifeguarding task can only help reduce the loss of life resulting from drowning.

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