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# **Lights and Siren: A Review of Emergency Vehicle Warning Systems**

Emergency medical services providers routinely respond to emergencies using lights and siren. This practice is not without risk of collision. Audible and visual warning devices and vehicle markings are integral to efficient negotiation of traffic and reduction of collision risk. An understanding of warning system characteristics is necessary to implement appropriate guidelines for prehospital transportation systems. The pertinent literature on emergency vehicle warning systems is reviewed, with emphasis on potential health hazards associated with these techniques. Important findings inferred from the literature are 1) red flashing lights alone may not be as effective as other color combinations, 2) there are no data to support a seizure risk with strobe lights, 3) lime-yellow is probably superior to traditional emergency vehicle colors, 4) the siren is an extremely limited warning device, and 5) exposure to siren noise can cause hearing loss. Emergency physicians must ensure that emergency medical services transportation systems consider the pertinent literature on emergency vehicle warning systems.

## **Introduction**

Emergency medical services (EMS) providers routinely respond to and from the scene of a medical emergency using lights and siren. This practice is not without risk, as numerous ambulance collisions have been reported, often with tragic outcome (1,2). Emergency vehicles are specifically painted, marked, and equipped with audible and visible warning devices to assist them as they negotiate traffic. Data suggest that intersections pose the greatest collision risk (1,2) and that emergency vehicles are more likely to be struck by another vehicle than vice versa (3). Therefore, the ability of another driver to detect and safely avoid an approaching emergency vehicle is crucial to collision prevention. A review of the literature, however, indicates that the physician-level emergency medicine literature has not adequately addressed this issue, although anecdotal and nonanalytical information on vehicle operations appears in the EMS, fire, and police service literature (1).

As medical director or medical control provider, the emergency physician has an important role in the development and implementation of EMS systems to include prehospital emergency vehicle operations (4,5). Many of the beliefs regarding emergency vehicle warning systems held by EMS personnel are based on anecdotes and unsupported data. State and local laws and rules regarding lights and sirens lack uniformity (6), and their origins may be traced to many years before modern research was conducted.

Motorists and pedestrians represent the greatest threat to safe and efficient responses by emergency vehicles. Assuming pedestrians and drivers understand their responsibilities to yield to emergency vehicles, the primary objectives of a warning system are gaining attention; identification; projecting size, distance, speed, and direction of travel; and obtaining a proper reaction (7). Emergency vehicle markings and warning devices must be evaluated against these factors when considering the potential

for collision risk reduction.

This article reviews the pertinent biomedical and safety literature on emergency vehicle markings and warning techniques. The potential of these systems to prevent ambulance collisions is discussed. Special attention is given to the health hazards associated with these warning devices. Recommendations for current applications and future study are presented.

## Visual Warning Systems

### Lights

It is estimated that more than 90% of the sensory input to a motor vehicle driver is obtained visually (8). Thus, visual warning systems are likely to be crucial in alerting drivers to the approaching ambulance. Hills describes visibility, conspicuity, driver attention and field dependence, and driver expectancy as the factors determining whether an object is perceived appropriately (8). Visibility takes into account an object's visual size, luminance, color contrast (of object and background), and glare. Conspicuity refers to the amount of associated distractions (ie, camouflage). Unlike driver attention and expectancy, visibility and conspicuity must be considered in a warning technique's design because these factors are not highly dependent on driver behavior.

Federal guidelines provide for minimal ambulance lighting standards (9), but some controversy exists over the usefulness of these specifications (10). Furthermore, the federal specifications do not apply to other emergency vehicle types such as fire and rescue apparatus. Allen describes general considerations of light signal technique such as angle of visibility and mounting height (11), and detailed discussions of the topic are available from the federal government (12,13).

Flashing lights have been shown to be superior to steady signals in gaining attention, and this is generally accepted (14,15). Most but not all authorities believe that lights visible from the same side of the vehicle should flash in unison so as to "outline" the vehicle (6,7,10,11). However, Solomon cautions against the excessive use of lights visible from any one angle, suggesting that glare and dazzle may diminish visibility (10). Laboratory data lend support to this view, although no field studies are available (16). Flashing headlamps (high-beams) are frequent adjuncts to warning lights systems, although blinding oncoming drivers is a reported hazard (17).

The sensitivity of human vision peaks in the yellow-green portion of the spectrum. It is established that white is the most visible color for warning lights, followed by green, amber and red (18). White is effective in gaining attention but fails to identify the vehicle; it is therefore rarely used alone (7). Green is also visually effective but has similarly failed to gain widespread use because green is a "go," or "safe," color in our society (6). Yellow and red are colors that signify "danger," and this has led to their popularity as warning and caution identifiers. Yellow, at threshold levels, is often mistaken for a white flash (15). Red, too, has been criticized for being weakly visible (11), easily lost in tail lamps (7), and psychologically associated with rage and passion (10).

Combining colors to capitalize on both visibility and appropriate identification was examined by the California Highway Patrol in 1979 with promising results (19). This technique is frequently recommended (6,7,20); however, additional study on the optimal characteristics of a visible warning signal is needed.

Strobe rather than revolving-type incandescent lights have been criticized in the paraprofessional literature. One criticism is based on the brevity of strobes's powerful flash (20). A flash briefer than the 0.2-second visual-fixation speed could be missed (11). Other data suggest that most of a driver's visual field is not foveal, but rather peripheral (8), and therefore the initial attention-gaining effect of flashing lights would probably be independent of visual fixation. In addition, because brightness is a function of the time integral of luminous output (21), a strobe's high output would be expected to compensate its brief flash duration.

Muhler and Berkhout concluded that both strobe and incandescent lights had acceptable properties for emergency vehicle duty (22). Little objective data are available to suggest superiority of one light source over another.

Another more serious criticism of strobe lights is their suggested potential to trigger seizures in photosensitive patients (20,23,24). In fact, there are no reported cases in the physician-level medical literature; thus, the danger is not universally accepted (25). The concern appears to be based on the routine laboratory use of stroboscopic equipment to elicit seizures and EEG changes in certain individuals (23,25). Approximately 5% of the epileptic population is in some manner photosensitive (26). By far, the most common mechanism described is television-induced seizures, followed by seizures caused by sunlight and artificial lights (26).

The range of effective flash frequency for most patients is 6 to 40 Hz (26), which is far faster than typical emergency vehicle devices (25). In a recent series of 93 photosensitive patients, eight were reported to be sensitive to artificial light (in combination with or without sunlight), and none was reported to be sensitive to warning flashes (27).

EEG changes are commonly elicited by the stroboscope but are generally accepted to be without pathological consequence when induced in otherwise seizure-free individuals (27). They are not likely to affect driving (28), aircraft piloting (29), or other daily activities (30). Strobe lights appear to be no more likely to induce seizures than any similar flashing device (29,31). One reported effect of a strobe light on patient care was direct electrical interference with an ambulance ECG and did not involve the light output of the strobe (32).

## Markings

The color and markings of an emergency vehicle are important elements in the ability of motorist to detect and identify the vehicle. Ambulances in particular are prone to confusion because the body configuration resembles that of commercial vehicles (33). The appropriate color for emergency vehicles has been discussed mostly in the fire service literature (34,35).

Solomon (36) has championed the cause for improving vehicle visibility and provides convincing arguments for the lime-yellow color seen on some emergency vehicles. In 1984, he reported a study of collision rates in nine large fire departments. Those using lime-yellow vehicles had less than half the number of collisions that departments with traditional red vehicles (35). Although key methods and statistical information were not reported, these findings are consistent with insurance studies demonstrating fewer automobile collisions in white and yellow cars (11).

Highway studies indicate that cream, yellow, and white objects are most visible (8,37). Acceptance of lime-yellow has become wide-spread; the Federal Aviation Administration (38), armed services fire apparatus, and approximately 50% of new fire service vehicles are painted in this color (34). In 1989, the American Optometric Association passed a resolution supporting the use of lime-yellow (36).

Federal specifications state that ambulances be painted white with a horizontal orange stripe and blue lettering (9) and are therefore infrequently painted lime-yellow. The National Research Council was largely responsible for the technical content of the original ambulance guidelines published in 1973 (39). However, Solomon reported that the council responded to the question of ambulance colors in 1972 by stating that "the exterior color of the ambulance be primarily white with Omaha Orange trim" and that "no special research or references supported the choice of Omaha Orange (10)." Nevertheless, this painting scheme was adopted as the standard.

State regulations generally do not embrace federal guidelines; thus, other painting schemes are frequently seen on nonfederal ambulances. The visibility and conspicuity of these various color combinations have not been evaluated systematically, although vehicle identification is probably diminished owing to nonstandard patterns and colors.

The multicolored ambulance, while distinctive (33), may suffer decreased conspicuity because of the effects of camouflage. Allen claimed that vehicles with two-tone paint patterns are likely to be less

visible than single-colored vehicles (11). Hills commented that the decreased conspicuity of a multicolored vehicle is more evident in urban environments (8). Adequate field studies to assess this issue have not been conducted.

The blue "star of life" emblem is widely used and accepted in EMS (33). The National Highway Traffic Safety Administration recommends use of the emblem to improve EMS vehicle identification (40). Whether such emblems affect visibility is unknown, although vehicle identification may be enhanced. The use of retroreflective material to improve visibility at night is required for ambulances (9). Allen recommends that all emergency vehicles be outlined with this material (11). Incomplete coverage is discouraged because it may contribute to the camouflage effect.

### **Audible Warning Systems**

Hearing is considered to be a primary warning sense. A loud auditory signal may exert an immediate arousing effect (42). Reaction time to a visual signal improved when an audible warning signal was included (43). Sirens and other audible warning devices have long been in use on emergency vehicles, and most state laws require their use during emergency runs (12). Federal specifications also require siren installation (9).

Recommended attributes of a warning signal include sufficient power and wide frequency spectrum to overcome masking noise (41), rapid rise of pitch (7), and relatively rapid cycling time (44). The recommended frequency range is between 1 and 4 kHz (45), which is consistent with the peak sensitivity of human hearing. It is thought that high frequencies are not localizable (41), and sound energy below 1 kHz is wasted (44). Electromechanical sirens, now largely replaced by electronic devices, may not achieve an optimal power spectrum and suffer from inadequate sound penetration (46). Proper speaker placement appears important (46), and guidelines have been suggested (7).

To be effective, a siren signal must compete with the masking noise generated by the road, car radios, and ventilation fans and must overcome modern sound insulation techniques. A US Department of Transportation (DOT) report (44, 47) showed that over a siren's effective frequency range, the average signal attenuation (through closed-windowed automobile bodies combined with typical masking noise) resulted in a maximal siren effective distance of siren penetration of only 8 to 12 m at urban intersections. Only modest improvement in the situation occurred at suburban intersections and straight-ahead highway conditions. These findings have been corroborated (46,48), and from the data a maximum safe entry speed of 10 mph (15 km/hr) for intersections is recommended (49). The Department of Transportation report concluded that sirens will never become an effective warning device.

The use of different siren modes (eg, wail, yelp, high-low) has been controversial. One commentator recommends different modes for different traffic conditions (50), and some studies have suggested that the high-low European-style siren is less effective than other modes (7,51). However, two informative studies showed no significant differences between various siren modes (44,52). A national consensus committee and other have recommended the high-low siren as the most appropriate emergency vehicle signal (53,54). Efforts to identify the optimal siren signal are likely to achieve only marginal improvements, given the overall limited effectiveness of audible warning devices.

Air horns are frequent adjuncts to siren on larger emergency vehicles. However, little has been written on this warning device. Some suggest that the dual-trumpet air-powered horn is optimal (7), whereas others caution against drowning out the siren at a crucial time with a simultaneous air horn blast (55). The lack of published data precludes any firm conclusions being drawn on air horn effectiveness.

The Department of Transportation study notes that the sounds of sirens result in community annoyance and sleep disturbance but concluded that the risk of hearing damage to the general public was insignificant (44). However, a federal study has demonstrated sound levels exceeding occupational standards for the ambulance driver (56). Four studies have linked hearing loss to siren-exposed EMS personnel (57-60). Simple measures to reduce the risk of exposure include mounting the siren speakers on the front grill (rather than the cabin roof) and closing the windows (44). Patients

and crew members in the rear compartment of the ambulance were considered to be at minimal risk of hearing loss (60). Studies to evaluate the long-term effectiveness of sound reduction measures are needed.

## Summary

Based on the literature reviewed, the following conclusions can be drawn. First, there is evidence to suggest that red flashing lights alone may not be optimal visual signals. Combinations with other, more visible colors may improve overall lighting effectiveness. Further study to determine a flashing signal's optimal characteristics may be indicated.

Second, evidence supporting a seizure risk with strobe lights appears unsubstantiated.

Third, there is acceptance for the color lime-yellow on emergency vehicles, and this is supported by experimental and field studies. Red is less visible, white and orange ambulances may also be less visible, particularly in urban environments. A study comparing the visibility and collision rates of lime-yellow with those of traditional ambulance colors would be helpful.

Fourth, several studies clearly demonstrate that the siren is a severely limited warning device, effective only at very short ranges and very low speeds. Differences in siren mode do not appear to be important.

Last, hearing loss in siren-exposed EMS personnel has been documented. Steps to reduce the risk must be implemented.

Emergency physicians must ensure that EMS transportation planning and operations consider the pertinent literature on emergency vehicle warning systems. Efforts to inform EMS personnel of current knowledge on warning systems must be included in all primary and continuing education programs and become an integral part of risk management and safety training.

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