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Determining optimum flash patterns for emergency service vehicles: An experimental investigation using high definition film

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ABSTRACT

An investigation of how emergency vehicle lighting (EVL) can be improved is reported with reference to an analysis of police vehicle road traffic accidents (Study 1). In Study 2, 37 regular drivers were shown film clips of a marked police vehicle, in which flash rate (1 Hz, 4 Hz) and pattern (single, triple pulse) were varied on the blue Light Emitting Diode (LED) roofbar. Results indicate a 4 Hz flash rate conveys greater urgency than a 1 Hz rate, while a 1 Hz, single flash combination was ranked the least urgent of all combinations. Participants claimed they would leave significantly more space before pulling out in front of an approaching police car (gap acceptance) in the 4 Hz single pulse condition in comparison to other EVL combinations. The preliminary implications for which flash characteristics could prove most optimal for emergency service use are discussed with regard to effects on driver perception and expected driving behaviour.

1. Introduction

1.1. The need for emergency vehicle lighting

The work of emergency service vehicles is inherently hazardous. A report by the Independent Police Complaints Commission (IPCC) states that there were between 11,000 and 19,000 police pursuits in England and Wales during 2005/06 and estimates between one and eleven pursuits out of every 1000 lead to a death (Docking et al., 2007). Statistics gathered by the Police Roll of Honour Trust (2010) indicate that between April 2000 and March 2010, there were 143 reported cases of Police Officers who died in the line of duty in the UK, the majority in road traffic accidents. Emergency medical services personnel also have a risk of occupational death that is disproportionally high, due largely to transportation-related fatalities (Slattery and Silver, 2009). Additionally traffic collisions are the second most common cause of death for fire fighters (Vrachnou, 2003). These findings are not simply due to the amount of driving undertaken by emergency services personnel. For ambulances, emergency driving carries a risk that is far greater than non-emergency ambulance driving (Kahn et al., 2001; Frøyland, 1982).

Research also indicates that emergency driving by the emergency services presents a risk to the general public. A recent report by the IPCC indicates that during the year 2008/2009, 40 members of the public died in England and Wales following road traffic accidents arising from police pursuits and other police traffic-related activity (IPCC, 2009). In terms of connotations for public spending, three Yorkshire Police forces in combination have reportedly spent £4.3 million on repairs, legal fees and compensation over a three year period, as a result of crashes involving 1965 police vehicles (Preece, 2010). There is a particular necessity for emergency vehicle lighting (EVL) to alert the public to the vehicle's presence and thereby reduce the potential for accidents. This is demonstrated by the finding that for accidents at intersections, ambulances are far more likely to be struck rather than strike another vehicle (Geis and Madsen, 2001). The importance of EVL as a warning system, together with the propensity of accidents involving emergency service vehicles indicates there is a justified requirement to improve its effectiveness.

1.2. Effectiveness of EVL

EVL has two primary functions in protecting the public and emergency service personnel: (1) to draw attention of nearby pedestrians and drivers; (2) to provide basic information about the situation to enable those drivers and pedestrians to take appropriate action (Cook et al., 1999). Research on both of these functions shall be reported in the next sections. Although the colour, number

Abbreviations: ANOVA, analysis of variance; EVL, emergency vehicle lighting; HD, high definition; SP, single pulse; TP, triple pulse; IPCC, Independent Police Complaints Commission; LED, Light Emitting Diode.

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and location of flashing lights on a vehicle can affect the ease with which it can be detected, in addition to whether it is viewed in peripheral or foveal vision, during daylight hours or particular weather conditions (Cook et al., 1999; DeLorenzo and Eilers, 1991; Kahn et al., 2001; Vrachnou, 2003; Wells, 2004; Ullman et al., 1998), the key focus of this research is flash pattern and flash speed.

1.2.1. Effectiveness in drawing attention of pedestrians/drivers

A key factor determining the efficacy of EVL, is whether it affords greater conspicuity of the emergency vehicle. Conspicuity refers to the target's size, luminance, contrast and colour in relation to its background (e.g. Cole and Hughes, 1984; MacDonald and Cole, 1988). EVL tends to pulse and there is support for the supposition that a flashing light affords greater conspicuity than a steady burning light of equivalent intensity (Schmidt-Clausen, 1999). Indeed the peripheral detection of motorbikes is doubled with the use of a flashing rather than steady headlamp (Donne and Fulton, 1988). This conspicuity improvement has also been observed with industrial machinery, the detection time of a moving mining machine was reduced by 75% when a warning system employing flashing lights was used (Sammarco et al., 2012). There is evidence to suggest the human visual system is hard-wired to pay special attention to flashing rather than steady lights, as exemplified by gaze patterns of infants (Teller, 1979; Teller and Movshon, 1986; Jouen, 1990). The greater conspicuity afforded by a pulsing rather than steady light would therefore appear to be an innate rather than learned response. However research attests to the situational nature of conspicuity, i.e. a flashing light will only stand out from its background if this does not contain an excess of flashing lights and it is dependent on the complexity of the road environment in general (Berkhout et al., 1999; Cook et al., 1999; Treisman, 1986; review in Enns, 1990). Accepting these situational variables, preliminary research suggests the characteristics of the flash rate and pattern of EVL affect its conspicuity or ease of detection, as discussed below. However there is a marked lack of research in this area and some findings conflict.

1) ***Detection according to flash rate***: The effect of flash rate on detection is complicated by its dual effect on apparent brightness, therefore flashing lights require additional intensity to be detected as quickly as a steady light (Paine and Fisher, 1996; Sagawa, 1999). Although their research only involved the testing of yellow and amber lights, Hanscom and Pain (1990) found that altering flash rates (60–100 cycles per minute) and light intensities did not have a measurable effect on observer responses. In contrast, Cook et al. (1999) found beacons with higher flash rates were more detectable in laboratory trials (from 1 Hz to 4 Hz). More recent research by an unnamed author reported in Wells' review (2004) also indicates that lights are detected more quickly when a faster flash rate is employed. There is a limit to the speed of flash rate that is advisable however. At 20 Hz the light will appear to be constant (thereby cancelling out the conspicuity gain), flash rates between 10 and 20 Hz are most likely to trigger an epileptogenic response in a person with epilepsy and rates above 5 Hz are associated with reports of increased eye-strain and headaches (Ice Ergonomics, 2002; Jeavons and Harding, 1975; Wells, 2004). In addition increasing flash rates are associated with increasing levels of glare and annoyance (Cook et al., 1999).
2) ***Detection according to flash pattern***: Multiple flashes rather than equally spaced single flashes tend to be used in aviation because they are perceived to be more conspicuous, which may be because the initial flash gains attention and the following flash directs gaze (King, 1999; Schmidt-Clausen, 1999). There is evidence to indicate that double pulse flash patterns are more conspicuous than single pulse, while sequential patterns (rather than concurrent) are detected more quickly and are rated as more attention-grabbing (Cook et al., 1999). However there is also the view that concurrent light flashes are more optimal for detection because they have the effect of outlining the vehicle (Lamm, 1983). Again the issue with enhancing conspicuity by altering flash characteristics is an increased risk of discomfort and disability glare (Cook et al.; Lamm).

1.2.2. Effectiveness in providing basic information about the situation to facilitate safe avoidance action

At present statistics suggest that EVL does not help to clear the path for emergency services on the public roads to the desired extent. For example ambulances observed in the U.S. completed their routes 43.5 s faster in one study, and 1 min, 46 s faster in another with the use of warning lights and sirens (Brown et al., 2000; Hunt et al., 1995). The larger difference in journey time was statistically significant but not considered to be of practical benefit (Brown et al., 2000). This research might indicate that drivers do not understand the urgency implied by lights and sirens, or it may indicate that some motorists do not make avoidance manoeuvres effectively. A natural reaction for some motorists is confusion and panic according to the claims data of NRMA insurance (Drive, 2008). Additionally if the emergency service vehicle does not allow the driver time to observe the warnings and make the manoeuvre, delays may occur. By way of illustration Green (2000) found it took approximately 1.5 s to move the foot from accelerator to brake pedal in response to surprise events.

There is evidence to suggest that flashing, non-emergency vehicle lights could facilitate safe avoidance action. In a video-based driving simulation, Isler and Starkey (2010) used flashing hazard lights to warn that the vehicle in front was braking: a 19% improvement in speed of response to the braking manoeuvre was observed in comparison to the standard warning of illuminated brake lights. Of course the improvement observed in Isler & Starkey's study may be primarily due to the additional illumination of hazard lights rather than their flash characteristics, however this does imply that vehicle lighting can be utilised to positively impact driver behaviour. In order to prevent accidents it would be preferable if emergency lighting discouraged driving behaviours that could be risky with a fast-moving vehicle, such as pulling out in front of it. This particular behaviour has been measured by asking participants when they would pull out in front of another vehicle at the last possible moment, a judgment termed 'gap acceptance' (Pietras, et al., 2006). This study found that this measure differentiated between attention-impaired and unimpaired older drivers, finding that time to contact values were shorter (i.e. gap acceptance values were riskier) amongst attention-impaired drivers.

1.2.3. Effectiveness in communicating hazard & urgency

Although there is a lack of research in this area, EVL could provide numerous benefits if it could convey more complex information such as the urgency of the situation, i.e. urgency perception (Cook et al., 1999, 2000). Research indicates that light colour affects perceived hazard and lighting technology affects perceived urgency (Chan and Ng, 2009; Ullman et al., 1998). There is evidence that flash rate and pattern of emergency lighting also affects perceptions of urgency. Cook and colleagues (1999) established that a blue light with a higher flash rate enhances perceived urgency in comparison to lower flash rates. More recent research also shows that hazard perception (i.e. how hazardous a situation appears to be) increases with increasing flash rates, with a particular impression of urgency achieved at 4 Hz (Chan and Ng, 2009).

Flash pattern research has suggested single pulse patterns between 4 Hz and 5 Hz enhance urgency perception (Van Cott and