Safety Science 47 (2009) 346–352

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Perceptions of implied hazard for visual and auditory alerting signals

Alan H.S. Chan *, Annie W.Y. Ng

Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, Kowloon Tong, Hong Kong

ARTICLE INFO

Article history:
Received 19 February 2008
Received in revised form 19 May 2008
Accepted 13 June 2008

Keywords:
Visual alerting signal
Auditory alerting signal
Hazard
Colour
Flashing

ABSTRACT

Visual and auditory alerts are increasingly important and have many applications, particularly in the presentation of hazard information in transportation and many industrial systems. This paper is concerned with the factors that govern the relative effectiveness of alerting signals involving various combinations of visual and auditory signals. The visual variables were colour, flash rate, and flash mode, combined with or without an auditory alarm. It was found that the subjects associated different levels of hazard with different alerting light colours, flash rates, flashing modes, and with combinations of auditory and visual alerts. A red flashing light was perceived as the most effective hazard warning colour, with yellow and blue warning lights indicative of less hazardous situations. The faster the flash rate, the greater is the hazard perceived. A flash rate of 60 fpm (flashes per minute) was not as effective as the rates of 180 and 240 fpm, and 240 fpm was the most effective. This implies that hazard warning signal should flash at well above 60 fpm. Having a breakup in the flashing pattern so as to provide a double or triple flash mode also increases the effectiveness of the signal. There were significant interactions between the alert variables used. The difference in perceived hazard levels for the colours blue and yellow were statistically non significant, but blue was more effective in conveying hazard message than yellow at the high flash rates. When accompanied with auditory alarms, blue and yellow were perceived to convey the same perception level of hazard as red without auditory alarms. The effect of colour on perceived hazard was also found to vary with flash mode. As compared to either visual signal alone or a visual signal with other types of acoustic alarms, a siren type of auditory alarm was found more effective for eliciting perception of hazards. There was evidence that presenting alerting signal in triple-flash mode and at high flash rate could be annoying and might not help improving hazard awareness.

1. Introduction

Visual and auditory alerting signals assist in the detection of anticipated stimuli (Papastavrou and Lehto, 1996) and are vital in traffic control and play an important role in many other situations. A number of studies (Hunt et al., 1995; Loeb and Fitch, 2002; Belz et al., 2003) have shown the benefits of combining visual and auditory signals in a clinical environment, for vehicle braking system, and for emergency situations, as compared to using either visual or auditory signal alone. In general, these studies have focused on the use of auditory enhancements for visual signals to minimize reaction time in human–machine systems. However, the perceived urgency, danger, or lack of safe conditions associated with visual and auditory signals have not been fully investigated.

Colour and flashing are two important and common means of coding visual alerting signals in daily life. Colour is particularly useful for memory coding and message recognition. The colours red, yellow and blue are frequently used in coding electrical and hydraulic equipment, and for marking safety hazards (Woodson et al., 1992). International guidelines and standards are available for designers to follow when using colours (ISO 3864-1: 2002; ANSI Z535.1-2002). Red identifies stop and danger and is used for a variety of fire associated applications and apparatus. Yellow suggests physical hazard and caution, and blue connotes caution against starting, using, or moving equipment under repair or in use. However, it has been shown that cultural and geographical factors may have an effect on designer preferences and user perceptions for colours. Colour associations for some common concepts like danger, emergency and safety were studied by Chan et al. (2003). The results showed that Hong Kong Chinese, Koreans, and Thais did not generally share common colour-concept associations (Chan et al., 2003). For example, Hong Kong Chinese and Thais associated red with potential hazard and radiation hazard, whereas Korean associated orange with potential hazard and yellow with radiation hazard. In a study of population stereotypes for colours with Hong Kong Chinese subjects, Chan and Courtney (2001) showed that choice of colours did not conform with

* Corresponding author. Tel.: +852 2788 8439.
E-mail address: alan.chan@cityu.edu.hk (A.H.S. Chan).

0925-7535/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ssci.2008.06.003

international standards, and that the use of colour alone may not be sufficient to unambiguously represent information about hazard levels. In addition to colours, the use of flashing visual codes should be considered together with audible codes to increase perception of hazard, especially where urgency is to be conveyed. However, the combination of auditory alerting signals together with the use of red, yellow and blue, and the consequent perceived danger, urgency and unsafe condition level for the visual signals have not been reported. Therefore, the purpose of this study was to explore the use of visual and auditory alerting signals to effectively convey impressions of danger, urgency, and unsafe condition levels in warning systems.

Flashing produces a rhythmic light pattern in which the total duration of light in a period is less than the total duration of darkness (ISO/IEC 18025: 2005). As a redundant cue, flashing was found to be superior to colour alone in attracting attention to objects in a display (Thackray and Touchstone, 1991) and in influencing the detectability of signal lights (Sanders and McCormick, 1993). In particular, flashing lights have long been used as a signal coding method in the marine, aviation, and road transport industries, and shown to be able to attract attention from a distance (Solomon, 2002). In the aviation industry, a red flashing light is an international signal for 'do not land' (HSE, 2001). In land transportation, a crosswalk warning system with flashing lights adjacent to a marked crossing is used to enhance road safety for pedestrians (Hakkert et al., 2002). Also, flashing lights are used to warn drivers to slow down and give way at rail crossings. Unselt and Beier (2003) showed that flashing brake lights significantly minimized drivers' reaction times in emergency braking compared with conventional brake lights. In the design of flashing lights, some characteristics such as flash rate and flash mode have been shown to influence detectability. Flash rate is the number of on-off cycles per minute. Most flashing signals have been designed for operation at flash rates between 60 and 180 flashes per minute (fpm) (Howett et al., 1978). The United Nations Economic Commission for Europe (UNECE, 2002) reported that typical flash rates for xenon beacons are 1–2 flashes per second (Hz), and that higher flash rates could be used to improve warning beacon detection time. It was recommended that flash rates of 1.0–1.6 Hz, 2.2–2.8 Hz, and 3.3–4.0 Hz be used in conditions requiring minimum, intermediate, and highest level of warning beacon conspicuity, respectively. It was, therefore, hypothesized here that the perceived danger, urgency and unsafe condition levels for an alerting signal would increase with flash rate of visual signals.

Apart from a single flash signal cycle, manufactures of signal lights and strobes have developed double or even multiple flash units by spreading the total flash intensity out over two or more closely spaced flashes per cycle. The flash 'on' times can be increased through the use of multiple flashes (Wells, 2004) and it has been suggested that double flashes are more effective than single flashes because the first flash directs subject's attention and the second one gives precise information of the flashing position (CIE, 1999). Therefore, the hypothesis here was that the perceived danger, urgency and unsafe condition levels for an alerting signal would increase with number of flashes in a cycle.

In addition to the use of colour or visual signals, audible signals may be necessary where safety of persons or the environment is concerned. Auditory warnings are widely used in transport, health care, and industrial environments as they have an immediate arousing effect (Sanders, 1975). Edworthy and Hellier (2006) identified three common types of sound for the design of alarms, namely speech, auditory icon, and abstract sound. An auditory icon is a sound which has some association to its function. Typical examples of auditory icons include ambulance siren and church bells ringing (Goldstein et al., 2003). An abstract sound such as pulse, tone, beep and buzz, was not thought to convey any specific type of meaning to listeners (McKeown, 2005). Both the auditory icon and abstract sound are categorized as non-speech sound or non-verbal auditory alarms (Brewster, 1997; Arrabito et al., 2004), and are commonly used in work environments where there is typically a lot of background noise (Edworthy, 1994). In clinical situations, Mondor and Finley (2003), however, found that the perceived urgency of non-speech warning alarms commonly occurring in the operating rooms of hospitals was not consistent with the actual urgency as intended by the designer. Arrabito et al. (2004) investigated the conveyed level of urgency of five non-verbal auditory alarms (Crypto, Emergency Locator Transmitter, Low Rotor, Radalt, Selcal) used in helicopter environments, and found that the 'siren-like quality sounds' of the Emergency Locator Transmitter were judged as the most urgent. Belz et al. (1999) and Graham (1999) also revealed that people responded to auditory icons more quickly than abstract sounds, suggesting that auditory icons are perceived of having higher level of urgency than abstract sounds. Thus, it was hypothesized that the auditory icons would also be perceived to have higher danger and unsafe condition levels than the abstract sounds here.

On the use of auditory enhancements for visual signals, Brewster (1997) showed that the integrated display of graphical and auditory information could increase performance, reduce time to recover from errors, and overcome information overload as compared with the graphical display of information alone. Loeb and Fitch (2002) found that anaesthesia trainees identified clinical events more quickly with a combined visual and auditory display than with either signal alone. Hunt et al. (1995) found that ambulance transport time from the scene to an emergency department was faster with flashing red light and siren than that without light and siren. In a simulated driving task, drivers' brake response times improved when collision warning information was presented through both visual and auditory modalities (Belz et al., 2003). In a recent study of simultaneous and delayed presentation of visual and auditory signals, it was found that responses to simultaneous presentations of the two types of signals were faster and more accurate than those to delayed presentations, and that the use of redundant information presentation increased stimulation and improved accuracy and speed (Lee and Chan, 2008). Based on the findings of these previous studies, it was hypothesized here that combined visual–auditory signal would be more effectiveness than visual signal alone in conveying the perception of urgency, unsafe condition level, and danger.

2. Aim and objective

This research was to investigate perceptions of implied hazard for visual and auditory alerting signals. The objective was to study the effects of flash colour, flash rate, flash mode, and auditory alarm type on perceived danger, urgency, and unsafe condition levels for the observers:

(i) The perceived danger, urgency and unsafe condition levels for an alerting signal would increase with flash rate of visual signals (Hypothesis 1).
(ii) The perceived danger, urgency and unsafe condition levels for an alerting signal would increase with number of flashes in a cycle (Hypothesis 2).
(iii) The auditory icons would be perceived to have higher danger and unsafe condition levels than the abstract sounds (Hypothesis 3).
(iv) The combined visual–auditory signal would be more effective than visual signal alone in conveying the perception of urgency, unsafe condition level, and danger (Hypothesis 4).