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Degradation of fluorescent high-visibility colors used in safety garments for the Australian railway industry

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ABSTRACT

Introduction: This study investigated the compliance of four fluorescent orange high-visibility garment substrates that are predominantly used in the Australian railway industry. While Special Purpose Orange (SPO), a shade of the Fluorescent orange (Fl-orange) is recommended by most Australian states as the high-visibility background color of a safety garment, there appear to be variations in the background color of clothing used by line-workers and rail contractors. The color of the garment was assessed for compliance with the Australian Standard AS/NZS 1906.2.2010 for high-visibility materials for safety garments. The results were also compared with ANSI Z535.2011 and BS EN ISO 20471.2013 Standards. *Method:* Photometric and colorimetric assessments of the background color of the garment substrates were performed using a spectrophotometer and were evaluated for compliance with the Standards after washing and exposure to UV. *Results:* The spectrophotometry measurements showed that Fl-orange background color for all samples except one complied with the AS/NZS 1906.2 Standard for daytime high-visibility garments after 20 washes but failed to comply after exposure to UV. It was also found that the chromaticity coordinates of the corners of the Fl-orange color space, specified in the AS/NZS 1906.4.2010 Standard are much wider and yellower when compared with the ANSI Z535.1.2011 and BS EN ISO 20471.2013 Standards. The sample that failed to comply with the Australian and American Standards however complied with the ISO Standard. *Practical Applications:* Irrespective of the Standard used, the research has shown the degrading effect of washing and light exposure and raises the questions as to how regularly, and under what conditions high-visibility garments need to be replaced. These findings will provide information for safety garment manufacturers about the characteristics and performance of high-visibility safety garments which make them conspicuous during daytime use. This research recommends that colors for railway workers should be chosen based on the conspicuity, commercial viability, reproducibility and durability rather than simply adopting standards from other industry domains or other countries.

1. Introduction

1.1. Problem

In recent years, the significance of personal protective equipment (PPE) for accident prevention has been closely examined from multiple perspectives in the rail industry. These include improved methods for identifying hazards, inclusion of certain mandatory regulations, introduction of proper training schemes for relevant personnel, and periodic update of key PPE relevant to the industry. In particular, the appropriateness of high-visibility colors for PPE used by railway workers has gained momentum because there is no railway-specific Standard in Australia, and as a result there are inconsistencies in the supply.

As a consequence of the globalization of the textile sector, the opportunity to source PPE from predominantly delocalized suppliers has impacted on the consistency of the supply. Industries such as rail, road, and building are now seeing their supply of safety garments, particularly in terms of color vary. This issue has raised concerns regarding the appropriateness of clothing in terms of safety, product quality, and performance. Such inconsistencies are likely to affect the procurement processes in agencies and as a result can impact the regulatory policies within these industries. Also, overseas manufacturers are obliged to cater for the diverse requirements of high-visibility clothing because of the differences in national standards. Achieving color consistency is challenging and variations in the specified Standards across the globe will further complicate the supply.

The railway industry in Australia does not have specific safety clothing standards but refers to AS/NZS 1906.4.2010 'High-visibility materials for safety garments.' However, a number of rail agencies predominantly recommend the use of a specific Fl-orange shade referred to as Special Purpose Orange (SPO) as the background color for high-visibility safety garments. This has added to the variability of the safety garments seen across the railway industry in Australia.

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High-visibility safety garments can include items such as vests, jackets and trousers, and coveralls. Some of this clothing requires additional features such as fire retardant and electrical safety properties. Such clothing may pose challenges in manufacture and in obtaining color consistency particularly if the base material is of a different fiber type. Although fluorescent colors can be obtained by various dye types to suit the different fibers, the durability of the color can be questionable.

1.2. Polices and standards

High-visibility clothing can be deemed as one key component of PPE, and is any clothing worn which comprises of highly reflective properties or a color that can be easily detected against any background. In the context of the rail industry, high-visibility clothing is intended to provide conspicuity of the wearer when viewed by the train operators during daylight and under illumination by headlights in the dark. The background color is required to be of a fluorescent material in order to be discernible for track or line-side work. Part of the exterior layer of the garment is required to consist of retro-reflective stripes strategically placed on the garment. As a result, the garments become much more conspicuous in relation to various background conditions during the day and are discernible in the dark for observers near an incident light source, such as headlights.

The selection and use of high-visibility clothing can vary between countries and may be subjected to local regulations. In the context of Fl-orange, the following section compares chromaticity coordinates and luminosity factor in three international standards in terms of the background color.

1.2.1. BS.EN.ISO20471. (2013)

The BS EN IS0 20,471.2013 is a revised version of the EN 471.2003 high-visibility PPE Standard formulated by the International Organisation for Standardization (ISO) committee and adopted by the British and the European communities. The Standard provides the photometric and colorimetric values for conspicuity-enhancing materials that are suitable for use in high-risk environments. This standard specifies three categories of garments for discernibility features in complex backgrounds and environments that have visually competing objects. The Standard, however, does not specify Fl-orange but instead states Fl-orange-red as one of the key fluorescent colors for background materials.

In recent years, the use of high-visibility clothing in the UK rail industry has become a mandatory requirement for all personal associated with track or line-side work. The UK rail industry has adopted GO/RT 3279 Standard, which is primarily based on the European Standard EN 471.2003. The Standard requires garments to meet at least Class 2 of the EN 471.2003 Standard for the minimum area of high-visibility materials used in a garment, and unlike the European Standard, that permits different background colors for high-visibility materials, it specifies the use of fluorescent orange for use in the rail industry.

1.2.2. ANSI.Z535.1. (2011)

ANSI Z 535 was first introduced in 1979 with the intention of developing general standards for the design; application; use of signs, colors, and symbols; for the identification and prevention of specific hazards. In this Standard, two sets of specifications for color are provided, namely 'restricted' and 'unrestricted.' The 'restricted' colors are identical with the compliant CIE specifications for fluorescent color relating to visual signaling. In such circumstances, restricted colors are recommended where the subject has to be distinguished from the three fluorescent colors such as red, orange and yellow used together in a single system.

1.2.3. AS/NZS1906.4. (2010)

The adoption of high-visibility garments for use in the rail industry in Australia may have occurred as a result of the recognition of the various safety general standards introduced in the 1980's. Currently there is a mandatory requirement that all personnel working in close proximity to moving locomotives must wear high-visibility clothing in accordance with the general safety standards AS/NZS 1906.4.2010.

In 1997, AS/NZS 1906.4 titled 'Retro-reflective Materials and Devices for Road-traffic Control Purpose,' with a focus on 'High-visibility Materials for Safety Garments' was introduced. Specifications on chromaticity, photometry, color fastness and other characteristics of color were provided as minimum requirements for manufacturers, suppliers and consumers.

This standard classifies high-visibility materials into the following categories;

- Class F relates to high daytime-visibility fluorescent materials
- Class F (W) relates to high daytime visibility fluorescent materials that meet the requirements for Class F and are suitable for wet weather use
- Class R relates to retro-reflective materials for night-time use
- Class RF relates to combined performance of retro-reflective and fluorescent materials satisfying both day and night-time conditions
- Class NF relates to high daytime visibility of non-fluorescent materials.

One of the key differences of this Standard when compared with ANSI Z535.1.2011or BS EN IS0 20,471.2013 Standards is, that it allows manufacturers to source or supply daytime visibility materials made of either cotton, linen or equivalent manmade fibers AS/NZS1906.4. (2010).

The chromaticity coordinates of the corners of the Fl-orange color space and the luminance factor for the above mentioned standards are shown in Table 1.

1.3. Relevant studies—Significance of color for safety garments

This section reviews research conducted on safety colors in a variety of industrial domains, and the significance of conspicuity. A number of studies relevant in terms of choice and performance of different high-visibility colors have become the foundation for the development of many industry-specific safety clothing standards.

Killeen's research on 'emergency vehicle conspicuity,' reviewed four colors primarily used as safety colors (as shown in Fig. 1) to increase visibility and conspicuity (Killeen, 2005; USFA, 2009).

Killeen stated that the human eye recognizes green–yellow better than any other color over a range of light conditions. Green–yellow is rare in nature and has the ability to contrast with most metropolitan and pastoral backgrounds. Yellow possesses an intense chromaticity

Table 1
Chromaticity coordinates of the corners of the fluorescent orange color space and minimum luminous factors.

Standards	Color	Chromaticity coordinates		Minimum luminance factor
		X	y	
BS ENIS0471.2013	Fl-orange–red	0.610	0.390	0.40
		0.535	0.375	
		0.570	0.340	
		0.655	0.345	
GO/RT 3279.2013	Fl-orange	0.610	0.390	0.40
		0.560	0.380	
		0.585	0.355	
		0.640	0.360	
ANSI Z535.1.2011	Restricted orange	0.610	0.390	0.40
		0.535	0.375	
		0.506	0.404	
		0.570	0.429	
AS/NZS 1906.4.2010	Fl-orange	0.610	0.390	0.40
		0.550	0.450	
		0.458	0.404	
		0.506	0.371	