TESTING THE RELATIVE CONSPICUITY OF ROAD WORKERS' SAFETY GARMENTS

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AN IMPORTANT NOTE FOR THE READER

This research detailed in this report was comissioned by Transit New Zealand when it had responsibility for funding roading in New Zealand. This funding is now the responsibility of Transfund New Zealand.

CONTENTS

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EXECUTIVE SUMMARY

1. Introduction

The present study arose from the concern that road workers should be provided with the most visible safety garments. This would make them more visible to vehicle drivers whose attention is likely to be attracted by a conspicuous colour in their field of vision. There is, surprisingly, very little research available which could assist in selecting the most suitable safety colour for road workers in different roading environments.

The aim of this study was therefore to compare the relative conspicuity of 8 different test-garments in different real-life traffic scenes using rural and urban backgrounds. One hundred and thirty participants (70 males; 60 females), aged between 18 and 40 years, took part in the main study and two follow-up studies. Visual acuity and colour vision prescreening tests were performed on all participants.

2. Method and Procedure

Laboratory tests were conducted with the participants seated in a driving simulator. Colour slide photographs of actual road scenes were used as stimuli. The colour values (Chromaticity co-ordinates on the CIE colour space) for each garment on the test-slides were measured with a Minolta Chromameter and compared with the New Zealand Standards on high visibility clothing. The colours of the high visibility test-garments were within the range of acceptable New Zealand standards.

Participants were required to perform a dual task to simulate the divided attention task encountered in a real driving situation, a central tracking task (driving simulation) and a peripheral task (scanning slides of road scenes to locate road workers). A single road worker wearing the different safety garments was located in 8 different positions against 8 different backgrounds (4 rural, 4 city) at a distance of 120 metres (first slide of a trial) and then at 80 metres (second slide).

The colours of the test-garments were not known to the participants in the main experiment (attention conspicuity task) while they were known in the first-follow up study (search conspicuity task). In the latter, the road worker was always wearing the fluorescent orange test-garment (first condition) or the fluorescent yellow test-garment (second condition) for all slide positions and against all backgrounds.

The second follow-up study comprised 2 groups. First, 5 participants with impaired colour vision followed the same experimental procedure as the participants in the main study, except the blue test-garment was replaced with a fluorescent red garment. The control group (5 parti- cipants) wore an eye tracker to enable examination of search strategies.

3. Results and Discussion

Results of the main study indicated that overall the fluorescent orange and the fluorescent yellow were more visible than any of the other test-garments. Overall mean detection time for the fluorescent orange was slightly shorter than for the fluorescent yellow garment, but the difference was not statistically significant. Also, there was no significant difference between the detection times of these garments against any of the eight different backgrounds.

Overall, the fluorescent orange and fluorescent yellow garments with reflective stripes were less visible compared to the garments of the same colour but without such stripes. This was particularly noticeable against brighter backgrounds.

Fluorescent green had overall slower detection times than the fluorescent orange, yellow, and the fluorescent orange and yellow with reflective stripes. Although the fluorescent green was surprisingly conspicuous against many backgrounds, results were inconsistent. Variable detection times for fluorescent green were also found by other researchers who reported fluorescent green as highly conspicuous in some trials, but unsatisfactory in others.

Overall, detection times for the combination garment (fluorescent orange/yellow with reflective stripes were longer than for the fluorescent yellow or orange garments either with or without reflective stripes. It may be that from a distance, the two colours are less distinct, and blend to be seen as one colour that is less bright than each colour individually, and become less visible against both dark and bright backgrounds. Alternatively, the combination coloured shirt may not be associated with road workers.

The least visible garments were clearly the brightest (white) and the darkest (blue). They had the longest detection times for most of the backgrounds. White was less visible in the city compared to the rural background due to the white markings or white buildings. Blue often remained undetected. As the road workers in this study wore the safety garments over blue overalls (as frequently worn by road workers) there was no contrast between the blue overall and the blue safety garment. Further, as the foveal region is relatively blue-blind, and sensitivity to blue light diminishes in the periphery (Sperling, 1986), this result was expected. This result clearly demonstrates the importance of conspicuous safety garments being worn by road workers.

Detection times were shorter against rural backgrounds compared to city backgrounds. The difference was statistically significant. The shorter detection times were particularly evident in two rural conditions that were uncluttered. This result was expected, and was supported by both laboratory and real-life studies that consistently showed targets were less visible against a complex background, or where there was visual clutter.

An important result of the first follow-up study was that the detection time for the fluorescent orange garment was significantly shorter when participants knew the colour (search conspicuity task) compared to trials when they did not (attention conspicuity task). For the yellow garment search conspicuity trials also resulted in shorter mean detection times compared to the attention conspicuity trials. This difference did not quite reach statistical significance.

The second follow-up study did not reveal any differences between the detection times of colour vision impaired group of participants and control participants with normal vision. However, this prelimanary study used only a very small group of participants and a specific assessment of their colour vision impairment was beyond the scope of this study.

4. Recommendations and Conclusions

- The results from this study showing search conspicuity trials produced shorter detection times than attention conspicuity trials clearly strengthens the case for the use of a standard coloured safety garment so drivers can associate a certain colour with road workers, which in turn will increase detection rates and safety of road workers.

- Fluorescent orange and fluorescent yellow were the two most conspicuous colours. When results were combined, the mean detection time for the fluorescent orange was marginally shorter, but the difference did not reach statistical significance. When individual road scenes were evaluated, no clear pattern of responding was evident that clearly indicated either yellow or orange would be the better colour for a standardised garment. The aim of this reseach was to determine the most appropriate colour for roadworkers' safety garments. While it was not possible to make a clear decision between fluorescent orange and fluorescent yellow, they were clearly more visible than any other colours tested. The results indicated that the brighter fluorescent yellow (compared to fluorescent orange) was more visible against darker backgrounds, while fluorescent orange was more visible against brighter backgrounds.

- It was evident that conspicuity was reduced for garments with reflective stripes, especially against bright backgrounds. Therefore, it is recommended that reflective stripes not be used on safety garments worn in daylight conditions. If reflective stripes need to be on the garments, fluorescent orange would be the better choice as yellow with reflective stripes was less visible when the results were combined.

- Detection time for the fluorescent green was inconsistent, and use of this colour would not be recommended. Due to the considerably slower detection times for white and blue, neither of these colours would be recommended for use either. Neither would fluorescent red be recommended, as it is known that some people with colour impaired vision are unable to detect this colour.

- No comparisons were made in this study between experienced and inexperienced drivers. As it has been shown that increased central task complexity decreases peripheral task performance, it may be advantageous to determine whether there is a difference in safety garment detection times between experienced drivers and inexperienced drivers who may find the central driving task more complex.

ABSTRACT

One hundred and thirty participants (70 males; 60 females), aged between 18 and 40, took part in this research to test the relative conspicuity of eight different test-garments. A simulated driving situation was produced where the participants were required to fixate on a central task (simulating driving) while searching coloured slide photographs to detect a road worker wearing a test-garment, located in one of eight different positions, against 4 rural and 4 city road scenes.

The overall results showed that the fluorescent orange garment had the shortest detection time, with fluorescent (lime) yellow being the second shortest. This difference was not statistically significant. Reflective stripes on the garments impaired rather than improved daytime conspicuity. Fluorescent green and the combination garment (fluorescent orange/yellow with reflective stripes) were clearly less visible than the fluorescent yellow and orange garments. The darkest and brightest garments (blue and white) were the least visible garments against most backgrounds.

Detection times were shorter when the colour of the garments were known to the observers, and for garments against rural backgrounds compared to the more complex city backgrounds. The longest detection times were for road workers positioned at the far left and right positions, and shortest for the position on the top of the slide stimuli. No differences were found between the detection times of colour vision impaired participants compared to participants with normal vision. Analysis of some participants' eye movement behaviour revealed that they used mainly peripheral vision to detect the road workers. It was recommended that the colour of the safety garments be standardised and that either fluorescent orange or yellow be chosen.

1. INTRODUCTION

Work related accidents place a large financial burden on the Government, industries and individuals in New Zealand. Statistics for the year ending 30 June, 1995, reported by the Accident Rehabilitation and Compensation Insurance Corporation (1994 and 1995) indicate there were over 1.4 million registered claims which resulted in a total expenditure of $1.6 billion in accident compensation payments. Work related claims comprised 34% of all accidents reported, and 47% of costs.

Against this background, the Health and Safety in Employment Act 1992 provides promotion of safety and health at places of work. The Act puts the primary responsibility on the employer to provide a safe and healthy work environment by identifying, eliminating, isolating, or minimising work hazards (Occupational Safety & Health Service, 1992).

Road workers are under constant threat of death or injury as a result of being hit by vehicles. The hazard is compounded by high noise levels produced by machinery used in their work environment, eliminating auditory cues of approaching vehicles.

Consequently, they must rely on being clearly visible to vehicle drivers. The task of visually scanning the environment, however, is difficult due to possible obstructions in a driver's field of vision, and the complexity of the environment. In addition, drivers are required to perform a dual task where their attention is divided between driving the vehicle and scanning the environment.

1.1 The Origin of the Present Research

With respect to clothing worn by road workers, Transit New Zealand requirements state high visibility coloured clothing is to be worn at all times. High daytime visibility of safety garments is normally achieved by use of fluorescent materials[1]. Currently, however, there is not a schedule of approved safety clothing available to ensure compliance with this specified requirement. The Psychology Department at the University of Waikato was approached to conduct research to test the relative conspicuity of different coloured safety garments to be worn by road workers. The main application is intended to be public roads and similar situations where the wearer needs to be seen by drivers of motor vehicles with sufficient time to stop or take avoiding action.

1.2 Defining Visual Conspicuity

At any one time, attention can only be given to a small amount of the information present in a visual scene. For an object to gain our attention, therefore, it must be easily noticed, or conspicuous, among other objects in the environment. This aspect of conspicuity is evident in the dictionary definition: 'clearly visible, catching the eye, readily attracting attention' given in the International Webster New Encyclopaedic Dictionary of the English Language (1975, p.217). Conversely, inconspicuous objects may require considerable search time. Although there is agreement in the literature that a conspicuous object is one that attracts attention, there is no

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[1] Fluorescent material: Material that emits light at longer wavelengths than absorbed.

agreement in the literature that a conspicuous object is one that attracts attention, there is no agreed-upon method of measuring conspicuity.

Various measurements have been suggested. Early experimental research attempted to determine some absolute measure of conspicuity. Engel (1971) proposed that conspicuity of a target object could be specified by measurement of the area around a fixation point within which the object was noticed. The 'conspicuity area' concept was developed further by Jenkins and Cole (1982) who defined conspicuity as the 'probability' of seeing an object at a single glance, regardless of the object's angle of eccentricity from the line of sight. Other researchers measured search and reaction time (e.g., Baker, Morris & Stedman, 1960, cited in Cole & Hughes, 1984).

These studies assumed conspicuity was an object factor. A number of studies have shown the physical properties of objects, such as differences in size, luminance[2], number and colour, do influence conspicuity. However, an object found to be conspicuous for one background may not be equally conspicuous for another background. For example, a green ball on grass may be inconspicuous, whereas in other surroundings it may be conspicuous. The complexity of the background also influences conspicuity. Visual conspicuity, therefore, is relative to its background.

Further, as conspicuity involves the attraction of attention, it cannot be measured independently of the observer's state of attention. In this context, Cole and Hughes (1984) make a distinction between attention conspicuity and search conspicuity. They define search conspicuity as the property of an object that enables it to be quickly and reliably located when actively searched for. Attention conspicuity is the capacity of an object to attract attention even if unexpected.

In summary, the visual conspicuity of an object is determined by the physical properties of the object itself, the contrast between the object and its environment, and the attention of an observer.

1.3 Previous Research on Visual Conspicuity

1.3.1 Laboratory Research on Visual Conspicuity

Several experimental studies have explored the influence of background factors on target visibility by asking observers to locate a target presented on different backgrounds.

Jenkins and Cole (1982) examined the effect of background density (number) on target conspicuity. Target stimuli were the same shape and colour as the background elements, but differed in either size, luminance, or both. When the target disc differed in luminance from background discs, increased background density made the target disc less conspicuous. However, when the target differed in size, there was no effect on the conspicuity of target discs when background density changed.

In a later experiment, Cole and Jenkins (1984) made the backgrounds more complex by varying the size or luminance of background elements. The background density remained constant, and was the same as the maximum density used in the earlier experiment. They found variability in the

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[2] Luminance: the amount of light reflected from a surface

size of background elements had a substantial effect on the size difference necessary for a target to be detected. Variability in the luminance of the background elements did not affect target detection.

Using letter search tasks, Duncan and Humphreys (1989) showed that search efficiency decreased when similarity between targets and nontargets was increased, and conversely, search efficiency increased as the similarity between targets and nontargets decreased.

Treisman and Gelade (1980) showed that, when a simple detection operation was required, the colour dimension was particularly potent in making a target impervious to the effects of background details. Williams (1966) showed that observers selectively fixated objects much better on the basis of colour than on either size or shape. A series of experiments conducted by Nothdurft (1993) investigated the conspicuity of a single target from an array of texture patterns (lines or blobs). Results showed when colour variation in the background pattern was increased, targets had to display increased local colour contrast in order to be detected.

Backs and Walrath (1992) measured search time and the number of eye fixations to evaluate effects of colour coding in symbolic displays of varying difficulty. Results showed colour coding was superior to monochrome displays, as participants made fewer fixations and search time was reduced without affecting accuracy. It was also shown that colour coding was much more effective when participants were seeking multiple targets. This finding was consistent with a review conducted by Christ (1975) which noted that the beneficial effects of colour coding increased with display density (cited in Backs & Walrath, 1992). As colour guided the search process, Backs and Walrath (1992) concluded that colour should be used to identify broad classes of targets throughout the environment.

Generally, results from these studies have demonstrated that the greater the degree of physical difference between the target and background items, the more conspicuous the target is. In particular, the potential value of colour coding when the colour was relevant to the search task has been highlighted. Typically, however, stimulus in these studies composed of letters or relatively simple geometric forms, presented among irrelevant backgrounds. Consequently, results may not be fully generalisable to conspicuity of objects in real-life situations.

1.3.2 Conspicuity in Real-Life Settings

In a few field studies, visual-search performance has been examined directly in the real world. In other studies, real-life scenes have been simulated with slides or photographs.

Using projected slides of real environments in a laboratory study, Jenkins (1982) showed that it was the luminance contrast and not target luminance per se that determined the conspicuity of disc targets in real surroundings (cited in Cole & Hughes, 1984). After studying simulated visual search performance of Canadian search and rescue technicians, Stager and Hameluck (1986, cited in Donder, 1994) stated that both high luminance contrast and high colour contrast between a target and its background helped to improve target detection.

Boersema and Zwaga (1985) assessed the extent physical properties of the environment had on visual conspicuity, using slide photographs of railway station scenes, with routing signs as targets. Background complexity was systematically varied by adding poster advertisements to the scenes in differing number and size. Routing signs were presented in white on a blue background. Advertisements never contained the colour blue. Results showed that the conspicuity of the routing signs decreased as the number and size of advertisements increased, even though the colours of the routing signs were known.

In a later experiment, Boersema, Zwaga and Adams (1989) again assessed the distracting effects of advertisements on the conspicuity of routing signs. It was found that the presence of even small advertisements decreased the efficiency with which information could be found. Both search time and the number of eye fixations increased systematically with the number of advertisements present in the scene. Although these results showed that the conspicuity of the target object was reduced as background complexity was increased, the conspicuity of the routing information itself was not assessed.

Observations made during a field study conducted by Cole and Hughes (1984) showed that the character of the road exerted more influence in determining a target's conspicuity than either target size or reflectance. Conspicuity was very much reduced in the shopping centre sections compared to the same targets in the arterial road and residential sections. They considered these differences could be ascribed to either different task demands of driving (i.e., driver preoccupation) or different visual interference effects (i.e., visual clutter). Their study was not designed to distinguish between these two possible explanations, but they argued that visual clutter was the dominant factor in determining conspicuity at a given location. Cole and Hughes also found the angle of eccentricity of the object to the observer's line of sight was an important determinant, with the majority of observations occurring at small eccentricities.

1.3.3 Cognitive Factors

Experimental evidence has demonstrated the effect cognitive factors, such as pre-knowledge, expectation, and the state of attention of an observer, has on conspicuity.

Early laboratory work on searching for targets showed that giving information about the physical properties of a target greatly assisted a search task. For example, Green and Anderson (1956) and Smith (1962) demonstrated that when the colour of the target was known in advance, search times were considerably shorter than when it was unknown.

Results from a number of other studies also imply cognitive factors play a role in visual processing. Biederman, Glass, and Stacy (1973) showed that the detection rate of target objects was lower for jumbled versions of real-world scenes than for natural versions of the scenes. It was reported by Loftus and Mackworth (1978) that objects with a low probability of appearing in a certain environment were fixated earlier, more often, and with longer durations than objects having a high appearance probability. Results from these studies clearly indicate that pre-knowledge influences conspicuity.

Cole and Hughes (1984) defined two basic states of attention, one determined by the observer having no prior information about or expectation of the target object, and the other based on the observer being aware of the likely occurrence of the target objects, and being required to actively search for them. They argue these two states of attention correspond to attention and search conspicuity (defined in Section 1.2). During a field study in which both attention and search conspicuity were measured, these researchers reported that detection rates during search conspicuity trials were on average three times the number of attention conspicuity trials, which reflected the gains made by directed search. Cole and Hughes (1984) also suggested the demands of primary and of other tasks affected the state of attention, but did not include this variable in their study.

The results from Cole and Hughes (1984) study are relevant in two respects. First, from an experimental perspective, if a standard target object is used in a multi-trial conspicuity experiment, participants should be informed about relevant features of the target object as the task would alter from attention conspicuity to search conspicuity after the first trial. Second, from an applied perspective this finding supports the adoption of standard conspicuous safety garments for road workers. If all road workers were to wear the same conspicuous coloured safety garment, the task for drivers would encompass both attention and search conspicuity.

1.3.4 Relative Conspicuity of Safety Garments

It appears researchers have not paid much attention to the relative conspicuity of safety garments, as an extensive literature search yielded only 4 studies. One of these assessed relative conspicuity of clothing using different amounts of reflective tape, and three assessed the relative conspicuity of colours for safety clothing.

Shinar (1985) investigated night-time pedestrian visibility distance as a function of driver expectancy and clothing colour. Pedestrians wore either dark clothing, light clothing, or dark clothing with a reflective tag. Drivers in one group were informed that they should identify a pedestrian but were not warned the pedestrian may be wearing a tag. Drivers in the second group were warned that the pedestrian might be wearing a reflective tag, and they needed to identify the tag.

When expectancy was high, results showed slight visibility benefits of light clothing over dark clothing, and a large benefit of reflective tags over both. More important, detection distance of pedestrians was significantly reduced when drivers were not cued that the reflection was from a pedestrian. This finding demonstrated the importance of expectancy. Consequently, Shinar recommended a standardised, easily recognisable tag be used, so that it would be distinguishable from other reflective objects and immediately associated with a pedestrian or cyclist on the road.

Michon, Ernst and Koutstaal (1969) performed two laboratory experiments and one field experiment to assess the conspicuity of safety clothing for people who work on or near the road. In the first laboratory experiment two participants were tested to assess the longest distance at which a safety jacket worn by a road-worker may be detected. They used coloured paper chips of 10 x 4 cm^2 (scale 1:60, if 80cm long jacket worn) against two different backgrounds, light or grey concrete, and a cloudy sky near the horizon. Six colours were tested: white, yellow, fluorescent green-yellow, fluorescent orange, fluorescent red-orange, and fluorescent red. Results showed about 1.5 times as long a distance against the darker background. Fluorescent orange appeared to be the most visible colour, followed by fluorescent orange-red, fluorescent red, and yellow. White and fluorescent green-yellow appeared to be much less detectable.

Ten participants took part in the second experiment, 4 of whom had defective colour vision. Using a driving simulation condition, where participants were required to follow a moving spot of light, detection times of grey, white, yellow, fluorescent orange, fluorescent orange with a chevron ('V' shape), and fluorescent red colour chips were assessed. Background conditions were a grey pattern of pebbles under five lighting conditions, or a green pattern of foliage under two lighting conditions.

Results for the participants with normal colour vision showed fluorescent colours were detected more quickly than the non-fluorescent colours on the grey pebbles background, but this effect was not evident when the background was green. Detection times recorded for fluorescent orange with and without a chevron, were the shortest, with fluorescent red the second shortest. They also reported detection times were systematically shorter as the angular distance of a colour chip from the centre of the field of vision was greater. The results for the colour deficient participants showed detection times for fluorescent orange were the shortest, but detection times for yellow were shorter than those for fluorescent red for both background conditions.

In the third experiment, Michon et al. (1969) assessed conspicuity of four different colours, white, fluorescent and non-fluorescent green-yellow, fluorescent orange, and fluorescent red, in a driving situation. Four types of jackets were tested, 100% coloured, 75% coloured, and two different designs that were 50% coloured. Jackets were in 16 different positions along a 12 km track in settings of trees, heather, sky, or road. As in the laboratory experiment, the 'jackets' were not visible to the driver until the car was at a distance of 200 metres in one half of the locations or 100 metres in the other half. The 28 participants in this experiment were all employees of the Ministry of Traffic and related services.

Again, the shortest detection times were recorded for fluorescent orange, regardless of the jacket design. Detection times for both yellow and fluorescent green-yellow were significantly slower than fluorescent orange, and white had the slowest times. They also reported the numbers of undetected jackets as: 12 white, 6 yellow, 6 fluorescent green-yellow, and 0 fluorescent orange.

From these three experiments, the researchers concluded fluorescent orange and fluorescent red were most suitable for use in safety clothing for those with normal colour vision. As fluorescent red may cause difficulties to people with colour deficient vision, they suggested fluorescent orange was the better colour for traffic safety clothing.

More recently, Bradford, Isler, Kirk and Parker (1992) conducted a laboratory experiment to assess the relative conspicuity of six shirts for use as safety garments in the logging industry. The colours and designs of six shirts tested were fluorescent orange with a fluorescent yellow band, red and green, black with two fluorescent yellow 'v's, fluorescent yellow, white, and black. Participants performed a central tracking task while searching coloured slides for the test-shirts, displayed against one of two background conditions; a pine forest background or bush camouflage material. Eye movement equipment was used to record participant's visual fixations. This data was used to order the detection of each test shirt in each trial.

Results showed the dark coloured test shirts (red and green, black with two fluorescent yellow 'v's, and black) were less visible than the brighter coloured shirts against both background conditions. In each of the background conditions, the fluorescent yellow and white test-shirts were clearly the most conspicuous. Against the more realistic pine forest background, the fluorescent yellow test-shirt was seen first more often than the white shirt. Both the fluorescent yellow and white test shirts were considerably more visible than the fluorescent orange test shirt.

This appears to conflict with the findings of Michon et al. (1969) who concluded that fluorescent orange was the most conspicuous colour. However, results may have been different if complex backgrounds encountered by drivers were used.

The fourth study on conspicuity of safety garments was a field study and conducted by Januszke and Simpson-Lyttle (1996). Conspicuity was assessed by setting up mock work sites around which six 'workers' with different safety garments were positioned in an a curve like fashion. Groups of observers, seated in the rear of a vehicle, were driven past the site. The researchers recorded which colour garment they saw first and its position. The concluded that "surprisingly, there was no overwhelmingly most conspicuous colour, although the yellow, yellow green and green colours (all fluorescent) were the most visible to non colour defective observers. The fluorescent red-orange close weave jacket was almost as conspicuous as these, but the red-orange open weave was by far the least conspicuous"(p.9).

The literature reviewed has shown that object factors, background variables, and the state of attention of the observer influence relative conspicuity. In addition, physiological properties of the visual system must be taken into account when evaluating the conspicuity of colours.

1.4 The Visual System and Conspicuity

1.4.1 The Nature of Light Entering the Eyes

Within the sun's electromagnetic energy spectrum is a narrow band of wavelengths to which the eyes are sensitive, called the visible spectrum. The human eye sees visible light between approximately 360 and 760 nanometres (nm). Lights of different wavelengths are experienced as differences in colour. This is observed when sunlight is spread out (or diffracted) as it passes through a prism, or when we see a rainbow. As wavelengths increase across the visible spectrum, perception of colour changes from violet (the shortest visible wavelength) to blue, green, yellow, orange, and finally to red (the longest visible wavelength). Light entering the eye triggers a photochemical reaction in the rods and cones, the light receptors on the retina in the back of the eye. The rods and cones play different roles in vision. They vary in number (120-million rods, 6 million cones), in sensitivity to light (photo-sensitivity), in sensitivity to colours and brightness, and their distribution across the surface of the retina. The central part of the retina, called the fovea, contains only cones. Most of the cones are concentrated in the area around the fovea, then quickly fall off in density. Rods are more numerous than cones in the periphery. Each of these variables affects the conspicuity of target objects.

Cones are responsible for colour vision. Rods only distinguish black, white, and shades of grey. In low light conditions, when only rods will be active, no colour will be seen. When two lights differ in colour, they will not necessarily be perceived as being equally bright (impression of light intensity) when they are equal in luminance (amount of light reflected). For example, when blue and yellow lights are equally bright, the yellow light almost always appears to be brighter than the blue light (Coren & Ward, 1989).

In addition, rods and cones are maximally sensitive to differing wavelengths of light (Figure 1).

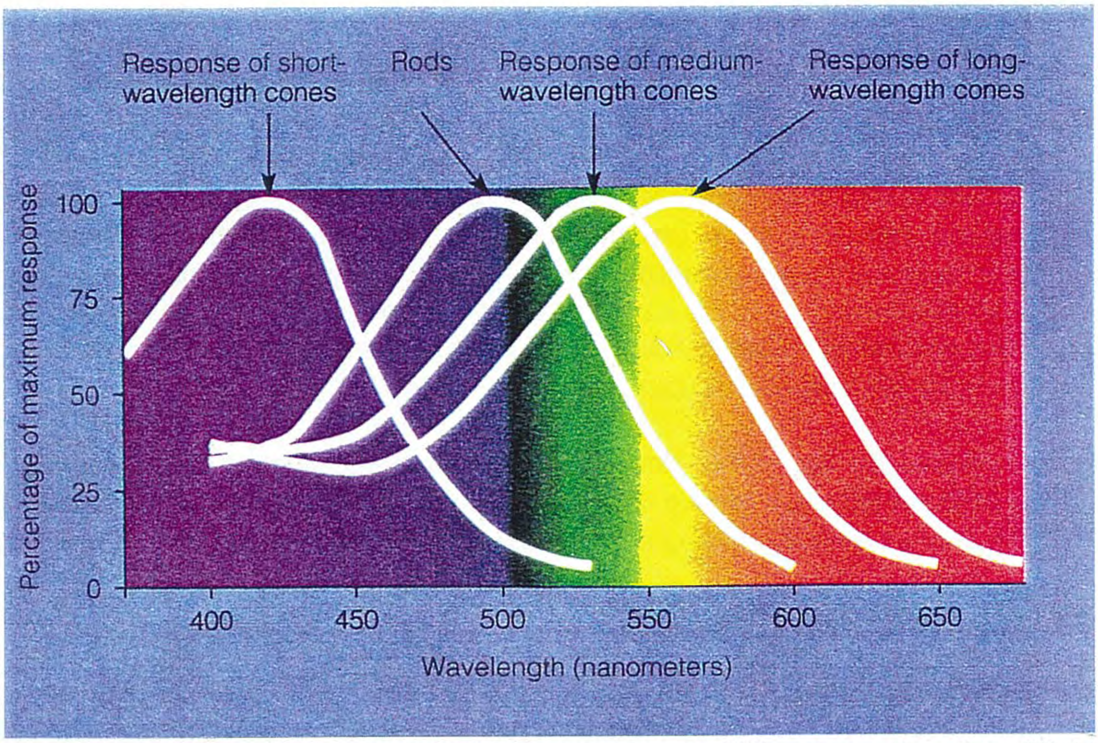

Figure 1. Rods and cones are maximally sensitive to different wavelengths of light (Kalat, 1995).

In daylight levels of light intensity, the eye is most sensitive to light of approximately 555 nm, which appears yellow-green. At this wavelength, the cones receive the greatest stimulation. Under dim light conditions where only the rods are operating and colour will not be seen, peak sensitivity is around 505 nm (blue-green) (Coren & Ward, 1989). Rods have a greater brightness sensitivity than cones throughout the colour spectrum, except at the red end, where rods are relatively insensitive (Smith, 1993).

These findings have prompted many cities to change the colour of their fire engines from the traditional red to yellow-green in order to increase the vehicles' visibility to both rods and cones in dim lighting (Smith, 1993).

Shuman (1991) reports that the American Optometric Association adopted a formal resolution supporting lime yellow for fire vehicles, and the U.S. Department of Transportation's Federal Aviation Administration drafted an advisory circular in 1986 which strongly recommends that yellowish-green be the vehicle colour standard for aircraft rescue and firefighting vehicles. In 1990, 40 percent of the new equipment ordered by fire departments was lime-yellow in colour. Further, it has been found that accident rates for red fire engines are double of those that are lime-yellow. Consequently, in 1989 the Cincinnati Insurance Co reduced insurance rates by 5% on lime-yellow fire-fighting vehicles in Sharon Township, USA.

The wavelengths of light are not the only factors that determine perception of brightness. Characteristics surrounding the stimuli can also alter the perceived brightness. That is, a bright

Characteristics surrounding the stimuli can also alter the perceived brightness. That is, a bright surround makes a target appear dimmer, and a dark surround makes a target appear lighter than they would if viewed in isolation.
Detection of an object is often initiated in the visual periphery. Because of the low visual acuity of the rods, this generally necessitates a rapid eye movement (saccade) to focus that portion of the visual field on the fovea where visual acuity is greatest. As rods are more sensitive to light than the cones, and are more plentiful in the periphery, peripheral targets appear brighter (Coren & Ward, 1989). However, because the periphery of the retina is made up predominantly of rods, there is no colour vision in the extreme periphery.

In addition, the co-operation of the foveal and peripheral visual system plays an important role in a person's visual performance in situations such as driving a vehicle. For example, Ikeda and Takeuchi (1975) showed that, in a dual task condition where the foveal stimulus was processed first, peripheral performance detoriated with increasing complexity of the foveal task.

1.4.2 Colour Vision

Physically, light can be described in terms of its wavelength, amplitude (or intensity) and purity. Psychologically, these dimensions correspond most closely to hue, brightness, and saturation. Hue is the perception of colour that is determined by the wavelength of light. The word colour in everyday life actually refers to hue. The height of the wave (amplitude or intensity) corresponds to brightness, or the light reflected from a surface. The greater the intensity, the brighter a colour appears. Light is also characterised by its saturation or purity, the number of different wavelengths that make up a particular colour. A fully saturated colour consists of light of only one wavelength. A colour becomes less saturated as other wavelengths of light are mixed with it. A highly saturated colour is vivid, a poorly saturated one is faded or washed out.

To standardise the procedure for specifying the colour created by the mixing of three colours, the International Commission of Illumination (or CIE, for the French title Commission International de l'Eclairage) developed a triangular colour space with a primary colour (red, blue, green) at each corner as shown in Figure 2, so a mixture of any three colours could be represented using two spatial coordinates. The periphery of the triangle represents saturated colours, with the colour becoming increasingly unsaturated toward the centre.

The three primaries are lights of 460 nm (blue), 530 nm (green), and 650 nm (red). The proportions of red and green primaries that must be added to the blue primary to match any given colour on the diagram are shown, respectively, on the horizontal and vertical axes. The proportion of blue can be calculated by subtracting the other two proportions from 100%. For example, to match the blue-green produced by a 490 nm light, the figure shows that the mixture must contain 5% red primary, 30% green primary, and 65% blue primary. The figure also shows that white is

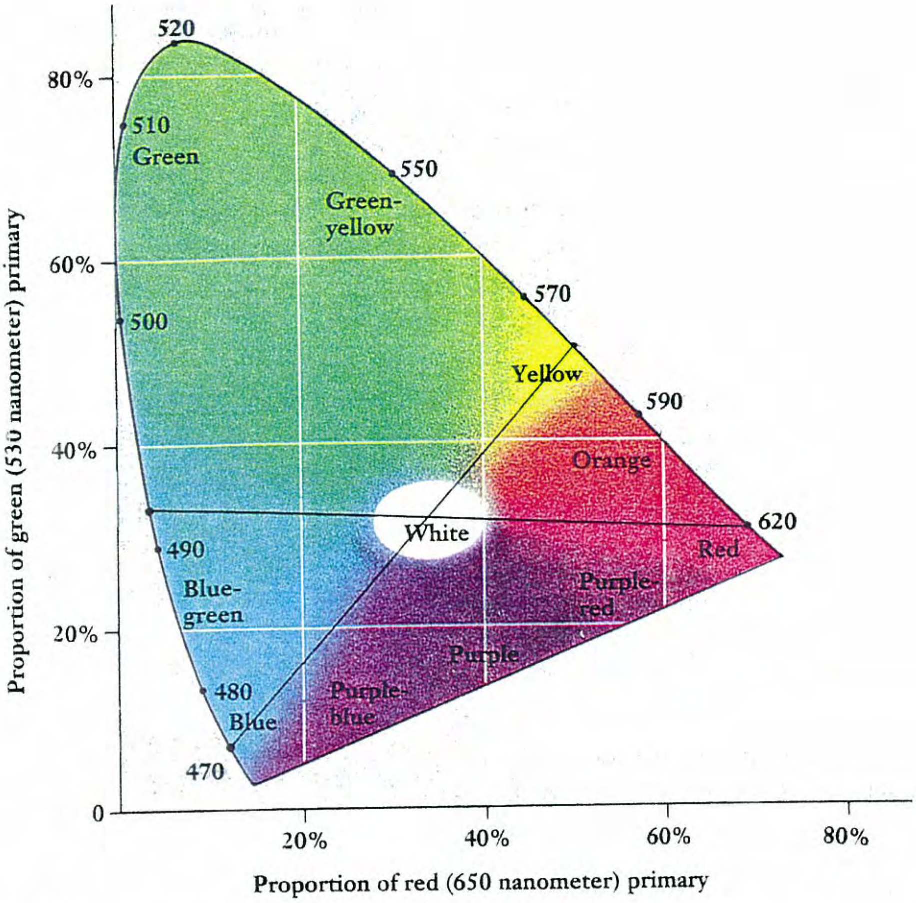

Figure 2. CIE triangular colour space (Gray, 1994).

produced by equal (33.3%) proportions of the three primaries.Because the cones are differentially distributed across the retina (e.g., Sperling, 1986), colour response is different over different portions of the eye. The central foveal region is relatively blue-blind, and sensitivity to blue light first increases, then decreases with increasing distance from the fovea. Sensitivity to green, red, and yellow light diminishes with increasing distance from the fovea, but not at the same angle for all colours. This observation has led to the development of the concept of colour zones (Figure 3), that is, the circumscribed areas of visual field within which a colour is normally perceived (Munn, 1966). The exact distance, however, depends on the size of the stimulus - the colours of larger stimuli can be discriminated farther out on the peripheral retina (Johnson, 1986).

1.4.3 Colour Vision Defects

People with normal vision (called trichomats) can distinguish between light and dark, red and green, and yellow and blue (Seamon & Kenrick, 1994). Between 6-8% of males fewer than 1% of females suffer various degrees of abnormal colour vision (Bloomer, 1990; Coren & Ward, 1989). About three-quarters of these people are simply poor at matching colours (a condition known as anomalous trichomatism) (Bloomer, 1990). For the others, colour blindness results from a deficiency in the red-green system, the yellow-blue system, or both (Smith, 1993).

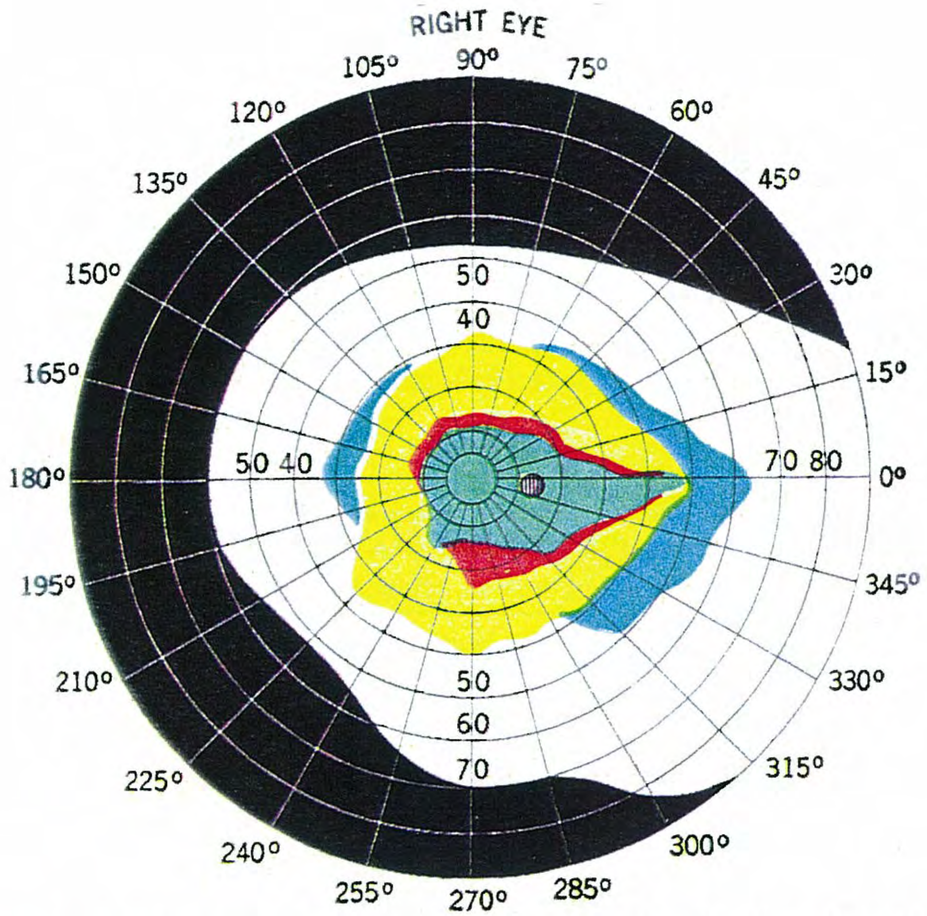

Figure 3. The colour zones in the right eye as viewed from the front (from Munn, 1966)

People whose colour deficiency is an inability to distinguish red from green, or yellow from blue, are called dichromats. A monochromat is sensitive only to the black-white system and is unable to see any colours at all. The most frequently occurring colour deficiency is in the red-green system where various shades of these colours appear greyish and cannot be differentiated from one another (Bloomer, 1990). They must rely on brightness for information. It is not possible to know how colours seen by an individual with dichromacy compare with those seen by a colour-normal observer.

Normal ageing also affects colour vision. This occurs as the lens of the eye becomes more yellow with age, resulting in lowered sensitivity to blues, and loss of cone pigment with age (Coren & Ward, 1989). Nearsighted people are more sensitive to the red end of the spectrum, and farsighted people to the blue end (Bloomer, 1990). Several diseases or physical conditions can also result in loss of colour discrimination (Coren & Ward, 1989).

1.5 New Zealand Standards

New Zealand Standards (NZS 5839: 1986) 'High Visibility Garments and Accessories for Road Users' specify the performance requirements for reflective materials used in the manufacture of garments or visibility accessories. It also specifies colours to be used on garments or visibility accessories intended to provide a higher visibility of persons on or near streets and highways during the daylight. The Standards state high visibility colours are ones which are the most useful in terms of a high luminance or a strong colour contrast with their background. There is no colour requirement for night-time use.

Day-time colour requirements and minimum luminance factors, as specified by the Standards, are presented in Table 1. The chromaticity co-ordinates (x,y) of the corners of the CIE Chromaticity colour space (Figure 2) define the specified colours. The luminance factor is defined as the ratio of the luminance of the material to that of a perfect reflecting diffuser illuminated and viewed under the same conditions.

Table 1. NZ Standards specify high visibility colours

COLOUR	CHROMATICITY CO-ORDINATES define the corner of the CIE colour space	LUMINANCE factor
White	x 0.350, 0.300, 0.290, 0.340 y 0.360, 0.310, 0.320, 0.370	0.75
Fluorescent orange	x 0.630, 0.551, 0.516, 0.584 y 0.369, 0.359, 0.394, 0.416	0.40
Fluorescent yellow	x 0.460, 0.424, 0.394, 0.416 y 0.540, 0.486, 0.516, 0.584	0.90

Note: the values given for fluorescent yellow are the colour commonly called fluorescent lime/yellow.

1.6 Study Objectives

This programme of research set out to investigate in a laboratory the relative conspicuity of eight different coloured test-garments (fluorescent orange, fluorescent yellow, fluorescent yellow/orange with reflective stripes, orange with reflective stripes, yellow with reflective stripes, fluorescent green, white, blue) under conditions that simulate the divided attention task encountered in a real driving situation. A central task involved a driving simulation, while a peripheral task involved scanning of static road scenes for crucial information, that is, detecting the test-garments of road workers located in different positions.

The specific objectives were:

- To determine the relative conspicuity of test-garments against rural and city road scenes in order to identify the most appropriate safety garment colour for road workers in New Zealand.
- To investigate the effects of reflective stripes on the relative conspicuity of test-garments.
- To investigate whether detection times of test-garments would be shorter if the colours of the test-garments were known to the participants.
- To assess the test-garments' conspicuity for colour vision-impaired drivers.
- To observe the eye movement behaviour of participants trying to detect test-garments in a driving simulation task.

2. METHOD

2.1 Participants and Visual Prescreening

The sample for the main study and the first follow-up study consisted of 60 male and 60 female volunteers with normal colour vision ranging in age from 18 to 45 years (mean age M= 26 years). Ten males (M=23 years) participated in the second follow-up study. Five had impaired colour vision, and five, used as a control group, had normal vision.

Participants were general staff, academic staff, and students, from the University of Waikato, as well as people they knew (friends/family) who were interested. Ethnic and socio-economic status variables were not taken into consideration. A consent form was used which outlined what was required of the participants, assured confidentiality, and acknowledged other ethical obligations. Participants who wore corrective lenses wore them during the testing. Each participant had a valid driver's license, and was given a $10 petrol voucher.

2.2 Apparatus and Experimental Set-up

Visual prescreening (visual acuity and colour vision) was conducted with the aid of a Vision Screener (Keystone VS-II, model 1135A). For the main testing, participants were seated in a driving simulator, which consisted of a seat, a dash board, steering wheel with a horn button, and foot pedals for accelerator, clutch and brake. They were required to perform a dual task which involved dividing the attention between a central tracking task (driving simulation) and a peripheral detection task (scanning slides of road scenes to locate road workers). The dual task paradigm was used to simulate the divided attention task encountered by vehicle drivers while driving and scanning the environment. Additionally, the central task was used to maintain the participant's attention and reduce the occurrence of chance detection of test-garments.

The central tracking task (Figure 4) was presented just below the projected test-slides with the road scenes for the peripheral detection task. Participants used the steering wheel, as they normally would when driving, trying to counteract the random and horizontal movements of a circle (3cm) so that the circle was kept around a stationery dot (1.3 cm). Each time the circle did not encompass the dot, a warning sound was emitted and the (central task) tracking error time was recorded. The random movements of circle were generated by a Pentium 100mHz computer as superposition of two sine waves of frequencies of 0.2 Hz and 0.5 Hz. A Sanyo LCD projector (model PLV-IP) was used to project the central task display just below the test-slide projection. The distance between the participant and the screen was 260 cm.

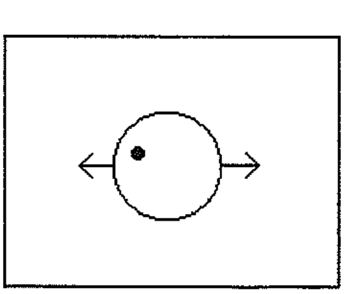

Figure 4. Display of the central tracking task

The peripheral detection task involved the scanning of projected slides (44cm x 68 cm) showing different work sites against different road scenes. The participants were instructed to detect a road worker wearing a different coloured test-garment on each of the slides. The road worker was located in eight different positions.

Nine sets of sixteen slide photographs were produced, using a tripod mounted Nikon F3 camera fitted with a 55 mm lens, and loaded with a Fujichrome Provia 100 Provessional RDP II film C34. Fujichrome was selected after tests comparing other films (Agfachrome 100 RS and Kodak Ektachrome Select 100) showed that Fujichrome produced the most accurate test-garment colours (fluorescent orange and yellow) on slides. These colours were within the range of the New Zealand Standards (see Table 2). The first eight sets of slides each showed eight mock work sites with one road worker, shown on a first slide from a distance of 120m and the on a second slide from a distance of 80m, against 8 different road scenes (4 rural and 4 city). The ninth set of slides contained only work sites (120m, 80m) without road workers, against 4 rural and 4 city backgrounds. A photograph was also taken of a road, showing grey metal chips and a centre white broken line, to be used for an 'inter-trial slide' between two test-slides.

Slides were presented using two Kodak Ektapro Slide Projectors (model 5000 and 7010). The projectors were controlled by a computer (Pentium 100mHz) displaying the slides for 6 seconds. Two projectors were used in order to allow smooth transitions between slides. The computer was also used to record the test-garment detection times and the tracking error times (central tracking task). The values of these two variables were combined with the values of the three independent variables (subject, group and condition numbers) on a raw data file which was then imported into a Statistica spreadsheet for further data analysis. Statistica is a statistics software package (Statistica software, manual, 1995) providing graphics and analysis facilities.

The colours and designs of the eight test-garments selected for the main experiment and the two follow-up experiments, as shown in Figure 5a-h, were: a = fluorescent orange (**fO**), b = fluorescent yellow (**fY**), c = fluorescent orange with reflective stripes (**fOr**), d = fluorescent yellow with reflective stripes (**fYr**), e = fluorescent orange/yellow with reflective stripes (**fO/Yr**), f = fluorescent green (**fG**), g = white (**W**), and h = blue (**B**).

There was also an fluorescent red test-garment (**fR**, Figure 6) which was used for the second follow-up study using colour vision-impaired participants. The fluorescent yellow was the colour commonly called fluorescent lime-yellow. All test-garments except the fluorescent green and the fluorescent red were New Zealand made by Protector Safety Ltd. They were all 70 cm long (front view).

The chromaticity values and the luminance values for the garment colours on the slides were measured with a Minolta chroma-meter CS100. They were measured from a distance of 170 cm and the chroma-meter recorded average (x,y chromaticity and luminance (cd/m^2) values over a circular target area with 1.4 cm diameter. These values are shown in Table 2 for the R9 position (i.e., the garments were in the 9 o'clock position and shown against a rural background, see Section 2.4.). The chromaticity values for the individual test-garment colours were the same for against all background conditions, while the absolute luminance values changed for all test-garments proportional to the brightness condition of the slides.


Figure 5a. Fluorescent orange **fO**

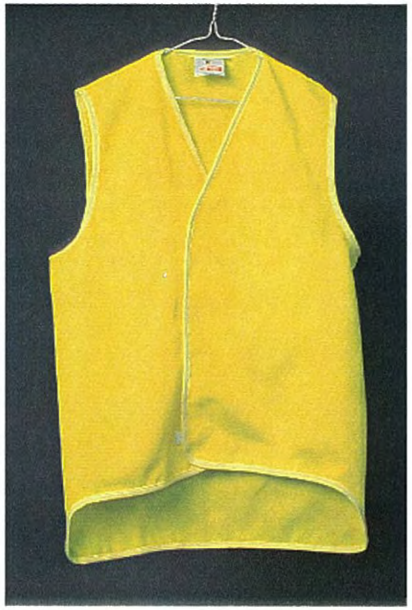
Figure 5b. Fluorescent yellow **fY**


Figure 5c. Fluorescent orange with reflective stripes **fOr**


Figure 5c. Fluorescent yellow with reflective stripes **fYr**


Figure 5e. Fluorescent yellow/ orange with refl. stripes **fO/Yr**


Figure 5f. Fluorescent green **fG**


Figure 5g. White **W**


Figure 5h. Blue **B**

Table 2. Chromaticity co-ordinates and luminance values for the test-garment colours

TEST-GARMENT COLOURS	CHROMATICITY CO-ORDINATES		LUMINANCE in cd/m^2
Fluorescent orange	x: 0.574	y: 0.413	9.44
Fluorescent yellow	x: 0.445	y: 0.485	12.00
Fluorescent orange, refl. stripes	x: 0.504	y: 0.395	9.88
Fluorescent yellow, refl. stripes	x: 0.429	y: 0.473	12.80
Fluorescent orange/ yellow, refl. stripes	x: 0.459	y: 0.432	10.97
Fluorescent green	x: 0.336	y: 0.519	6.86
White	x: 0.381	y: 0.410	18.97
Blue	x: 0.263	y: 0.230	0.54
Fluorescent red	x: 0.575	y: 0.336	4.61

The five control participants from the second follow-up study were fitted with an Applied Science laboratory (ASL) series 4100H head-mounted eye track recorder. This eye tracking system was connected to a 486 Mitac 25mz laptop computer. Scene and eye parameters were monitored on two Sony black and white video monitors (model PVM-122CE). A Mitsubishi VCR (model HS-E82, NZ), connected to the eye tracking system, was used to record the eye movements on video tape.

2.3 Experimental Design

The main study tested 96 participants (8 groups of 12 partcipants; 6 females and 6 males). They were required to scan test slides with rural and city road scenes and press the horn on the steering wheel as soon as they detected a road worker. There were 16 test-slides with eight different mock work site scenes with one road worker (shown on a first slide from a distance of 120 metres and then on a second slide from a distance of 80 metres). The 8 groups of participants performed the same experimental procedure except for each group the order of road workers' positions, test-garment colours and background conditions were changed so that over all groups, each test-garment was presented with equal frequency in each slide position and against each background condition. Additionally, there were 16 'catch trials' with slides of eight different mock work sites (4 rural scenes and 4 city scenes) shown each from two distances, (120m and 80m) without a road worker. These trials were randomly presented within the test-trials.

The first follow-up study used two groups of 12 participants who followed the same experimental procedure as the participants in the main experiment except that they were asked to detect a road worker who was always wearing the same test-garment (fluorescent yellow for the first group of participants and fluorescent orange for the second group). Therefore, they knew the colour of the garment to be detected (search conspicuity task).

The second follow-up study was an exploratory study, testing five colour vision-impaired participants who were identified as having mild or severe 'green-red defects'. They followed the same procedure as the participants of the first group in the main experiment except the blue test-garment was replaced with a fluorescent red (**fR**) garment (Figure 6). Five participants with normal vision acted as a control group. They were fitted with an eye tracker and their visual scanning behaviour was analysed.

Figure 6. Fluorescent red (**fR**)

2.4 Procedure

After visual prescreening tests, which took about 2 minutes per participant, the sequence of events was as follows. First, the participants were informed of the purpose of the experimental trials, that is, to detect a road worker in 16 slides while performing a driving task. Second, the participants completed a practice trial to learn the central tracking task (about 4 minutes). They were then shown a slide with lines indicating (clock) positions 9, 10, 11, 12, 1 , 2 , 3 and a centre point C (Figure 7) Road workers would be located near one of these 8 positions.

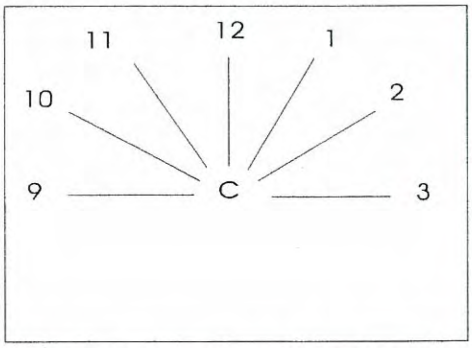

Figure 7. Road worker locations ('clock numbers') on the test-slides

The 'clock number' positions were used by participants to indicate where they detected a road worker. Finally, the participants completed the 16 experimental trials. Each trial was started with the inter-trial slide (grey road with central line), the next slide showed a work site either with a roadworker (test-trial) or without road worker ('catch trial'), first at the distance of 120 metres (first slide) and then at 80 metres (second slide). The whole procedure took about 40 minutes to complete.

3. RESULTS

The hundred and twenty participants (60 females and 60 males) completed the main study and two follow-up studies and provided the data for assessing the relative conspicuity of the eight different coloured test-garments.

The main study tested 96 participants (8 groups of 12 participants (6 females and 6 males in each group) and involved a dual task where they were required to fixate on a central task (simulating the driving) and to detect road workers on test-slides with rural and city road scenes. There were 16 test-slides with eight different mock work site scenes with a road worker (shown on a first slide from a distance of 120m and then on a second slide from a distance of 80m).

The 8 groups of participants performed the same experimental procedure except that for each group the order of road workers' positions, test-garment colours and background conditions were always changed so that over all groups, each test-garment was presented with equal frequency in each of the eight slide positions and against each background condition. Additionally, there were 16 'catch trials' with slides of eight different mock work sites (4 rural scenes and 4 city scenes, shown each from two distances, 120m and 80m) <u>without</u> a road worker. These were randomly presented within the test trials.

The first analysis of the main study (Section 3.1) concerned the overall mean detection time for each test-garment combined for all participants and background conditions (3.1.1).

The second analysis evaluated the detection times separately for each test-garment and background condition (3.2.2).

The third analysis assessed the effect of the rural and city backgrounds first overall for all test-garments combined and then for each test-garment separately (3.2.3).

The fourth analysis was concerned with the effect of the test-garment positions on the detection times and evaluated the central task error time performance. It also tested the data for a possible relationship between the detection times and tracking error time performances.

The first follow-up study (Section 3.2) used two groups of 12 participants who performed the same experimental procedure as the participants in the main experiment except they were asked to detect a road worker who was always wearing the same test-garment (fluorescent yellow for the first group of participants and fluorescent orange for the second group) against all background conditions.

The second follow-up study (Section 3.3) was an exploratory study, testing five colour vision-impaired participants who were identified as having mild or severe 'green-red defects' during the prescreening procedure. They followed the same procedure as the participants of the first group in the main experiment except that the blue test-garment was replaced with a fluorescent red garment. Five participants with normal vision acted as a control group. They were fitted with an eye tracker and their visual scanning behaviour was analysed during the experiment.

Before any testing was done, the participants were prescreened for visual acuity and colour vision. All selected participants for the main study and the first follow-up study had at least 20/40 corrected or uncorrected visual acuity for both eyes and normal colour vision. Five participants were identified as having some colour vision impairment and were further tested with the Ishihara colour vision test.

These tests showed that four of these participants had mild and one participant severe 'red-green defects' (deuteranope). They were used as participants for the second follow-up study. The control participants had normal vision.

3.1 Results of the Main Study

3.1.1 Overall Relative Conspicuity of the Test-Garments

Figure 8 shows the overall mean detection times for the eight test-garments shown at 120m (left bar) and 80m (right bar), combined for all background conditions. Most of the participants detected the roadworker at the longer distance of 120 m within the time limit of six seconds and therefore no response was required (response time =0) for the second trial where the roadworker appeared at 80 m.

The graph shows that the fluorescent orange garment (fO) had the shortest overall mean detection time at the 120 m distance, followed by the fluorescent yellow garment (fY) with a slightly longer mean detection time. The same coloured garments but with reflective stripes had longer mean detection times; fluorescent orange with reflective tape (fOr) followed first, then fluorescent yellow with reflective stripes (fYr). The fluorescent green garment (fG) had the next longest mean detection time, followed by the combination garment with the two colours fluorescent orange and yellow with reflective stripes (fO/Yr). The remaining two garments had clearly longer detection times, the white garment (W) was obviously not always easily detected and the dark blue garment (B) scored the longest overall mean detection time. The mean response times for the 120m trials correlated well with the response times for the 80 m trials except for the fOr garment which had a curiously long mean response time for the 80m trials.

In the following, only the 120m data were statistically analysed. A one-way statistical analysis of variance (ANOVA) on detection times with the different test-garment colours as grouping factor showed a clear overall effect of the test-garments colours on the detection times; $F(7,760)=8.85$, $p<0.001$.

Scheffe's post-hoc tests (Statistica software manual, 1995) was used in order determine which colours were more visible than other (contrast effects). The tests revealed that the overall detection times for B and W were significantly longer than those for any of the other garments, that is, it took significantly longer to detect B than W (Table 3 below).

Additionally, the fO garment had a significant shorter detection time than the fG and fO/Yr garments. There was no significant difference regarding overall detection time between fO and fY or the same coloured garments but with reflective stripes, fOr and fYr.

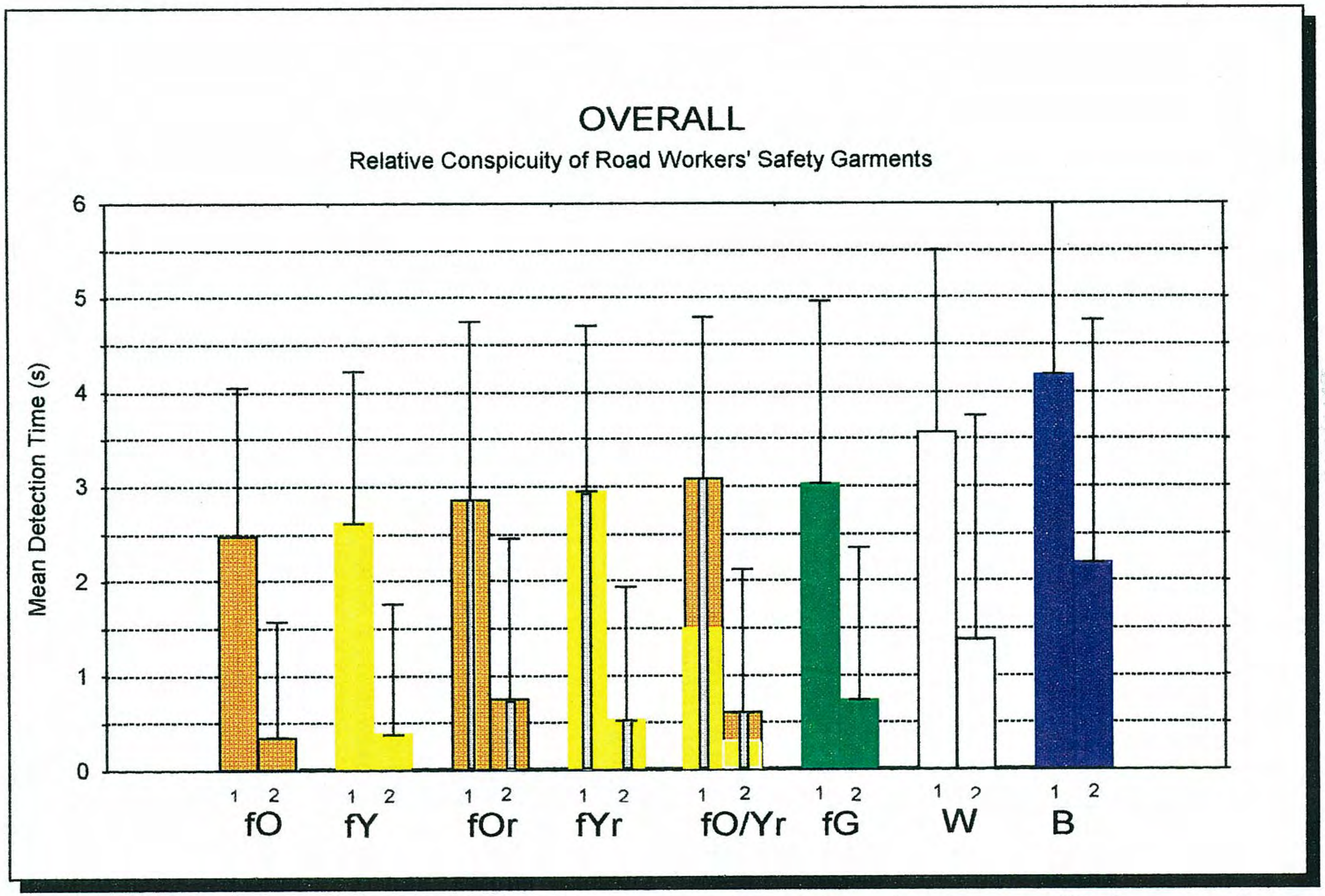

Figure 8. Mean detection time in seconds (standard deviation SD= ⊤) for each test-garment (fO=fluorescent Orange, fY=fluorescent Yellow, fOr=fluorescent Orange with reflective stripes, fYr=fluorescent Yellow with reflective stripes, fO/Yr= fluorescent Orange/Yellow with reflective stripes, fG=fluorescent Green, W=white, B=blue), and two viewing distances (1=120m and 2=80m).

Table 3. Comparisons of overall mean detection times, marked differences are significant: *=p<0.05; **=p<0.01; M=mean value (s), SD=standard deviation.

	fO M=2.4 SD=1.6	fY M=2.6 SD=1.6	fOr M=2.8 SD=1.8	fYr M=2.9 SD=1.7	fO/Yr M=3.0 SD=1.7	fG M=3.0 SD=1.9	W M=3.5 SD=1.9	B M=4.1 SD=1.9
fO	-------							
fY	.622	-------						
fOr	.144	.333	-------					
fYr	.071	.188	.727	-------				
fO/Yr	.023*	.075	.416	.642	-------			
fG	.036*	.107	.519	.768	.865	--------		
W	.000**	.000**	.006**	.017*	.055	.037*	--------	
B	.000**	.000**	.000**	.000**	.000**	.000*	.020*	--------

3.1.2 Relative Conspicuity of the Test-Garments for Each Background Condition

3.1.2.1 City background with test-garment in position 1 (condition C1)

Background condition C1 (Figure 9a) showed a moderately complex city scene with a roundabout, bright buildings and dark road foreground with many white road markings. The sky was overcast. The road worker was standing behind two orange cones in position 1 (o'clock) .

In this situation with the roadworker at 120m, the fluorescent yellow garment (fY) had the shortest mean detection time (Figure 9b, left column), followed by fluorescent orange. Next shortest times were for the combination fluorescent yellow/orange garment with reflective stripes (fO/Yr), and the fluorescent yellow garment with reflective stripes (fYr).The other garments were clearly less visible with similar mean detection times for fluorescent green (fG) and white (W), and the longest mean detection time for blue (B) test-garment. There was a similar result for the second trials with the roadworkers at 80m, except for the fO and fOr which had slightly longer response times than fYr and FO/Yr).

The following statistics concern only the 120m trials. A one-way ANOVA on the detection time revealed that there was an overall effect of the test-garment colours on the detection times; $F(7,88)= 8.85$, p<001. Post-hoc tests (Table 4) revealed that the colours fY, fO, and fO/Yr had significant shorter detection times than fG, B, and W.

3.1.2.2 Rural background with test-garment in position 2 (condition R2)

Background condition R2 (Figure 10a) showed a simple rural scene with dark green background and a grey/brown road foreground, with bright orange cones and bright road posts. The sky was overcast. The road worker was standing on the right side in position 2. In this simple rural scene with the roadworkers at 120m, all test-garments were easily detected (Figure 10b).

Figure 9a. Condition C1: City background with test-garment in position 1.

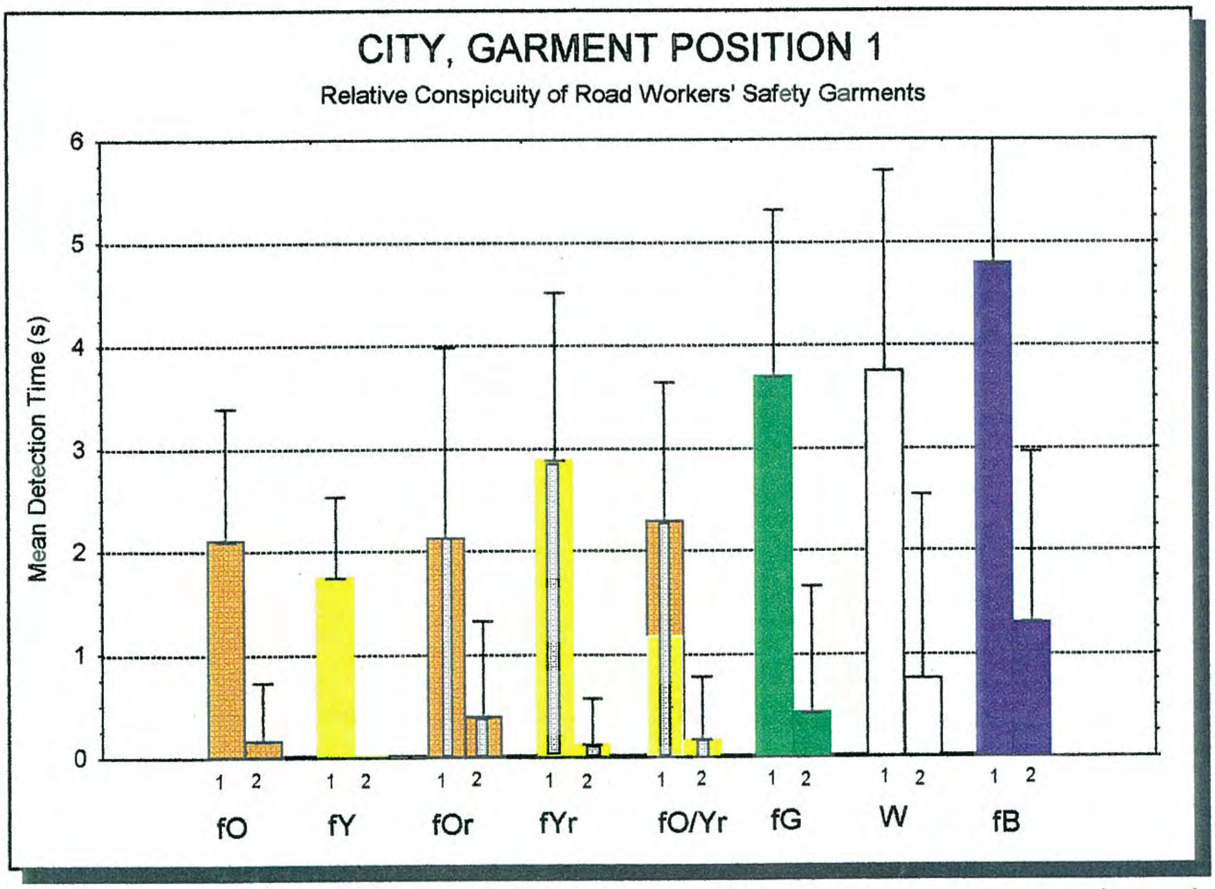

Figure 9b. Mean detection time (SD=⊤) for each test-garment in condition C1 (1=120m/2=80m).

Figure 10a. Condition R2: Rural background with test-garment in position 2.

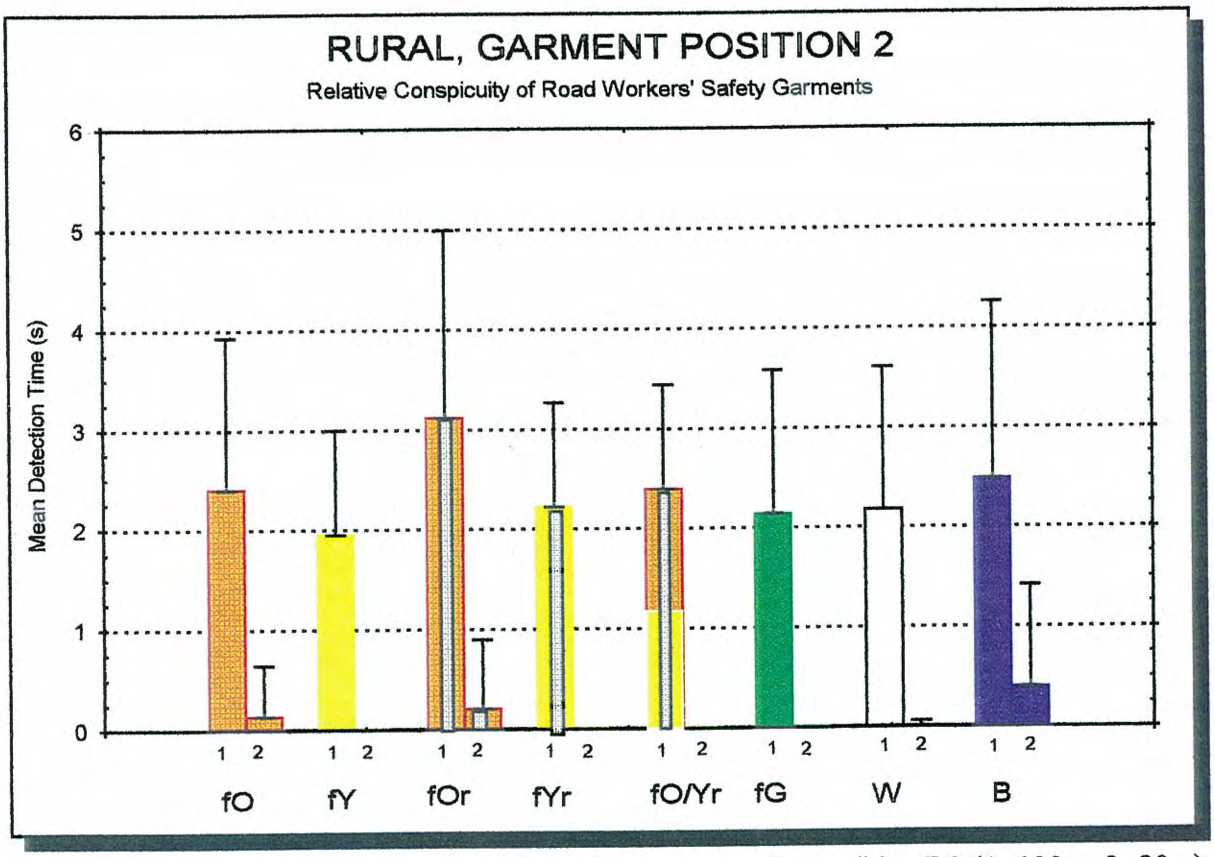

Figure 10b. Mean detection time (SD=┬)for each test-garment in condition R2 (1=120m, 2=80m).

Table 4. Condition C1: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value (s), SD=standard deviation

	fO M=2.1 SD=1.3	fY M=1.7 SD=0.7	fOr M=2.1 SD=1.8	fYr M=2.8 SD=1.6	fO/Yr M=2.3 SD=1.3	fG M=3.6 SD=1.6	W M=3.7 SD=1.9	B M=4.7 SD=1.8
fO	-------							
fY	.587	-------						
fOr	.954	.548	-------					
fYr	.225	.081	.247	-------				
fO/Yr	.755	.393	.799	.365	-------			
fG	.015*	.003**	.018*	.214	.033*	--------		
W	.012*	.002**	.014*	.180	.026*	.922	--------	
B	.000**	.000**	.000**	.004**	.000**	.092	.112	--------

They all had mean detection times of less than 3 seconds (except the fluorescent orange garment with reflective tape (fOr) which had a longer mean detection time of M=3.1s, standard deviation SD=1.8). The fluorescent yellow garment (fY) had the shortest mean detection time (M=1.8s, SD=2.0) followed by fluorescent green (fG; M=2.1s, SD=1.4), white (W; M=2.1s, SD=1.4) and the yellow garment with reflective stripes (fYr; M=2.2s, SD=1.0). The fluorescent yellow/orange combination garment with reflective stripes (fO/Yr; M=2.4s, SD=1.0) and the fluorescent orange (fO; M=2.4s, SD=1.5) show the same detection times, followed by the longest time for the blue (B) test- garment; M=2.4s, SD=1.7).The mean response times for the 80m trials were too short for a conclusive analysis.

A one-way ANOVA on the detection times revealed that there was <u>no</u> overall effect of the test-garments on the detection times, $F(7,88)= 0.5$, $p=0.82$, and therefore no significant differences between the garments regarding detection times can be obtained.

3.1.2.3 City background with test-garment in position 3 (condition C3)

Background condition C3 (Figure 11a) showed a dark and moderate complex city scene with bright orange traffic cones on the left side of the dark grey road. The sky was overcast and the road worker was on the far peripheral right side in position 3.

In this city situation with the roadworker at 120m, the fluorescent yellow garment (fY) had the shortest detection time (Figure 11b), followed by the fluorescent orange garment (fO), fluorescent orange with reflective stripes (fOr) and the orange/yellow combination garment with reflective stripes (fO/Yr). Fluoresent yellow with reflective tapes followed closely (fYr), whereas the fluorescent green (fG) and white (W) garments scored clearly longer mean detection times; and blue was never detected within the limit of six seconds. The response times for the 80 m trials

Figure 11a. Condition C3: City background with test-garment in position 3.

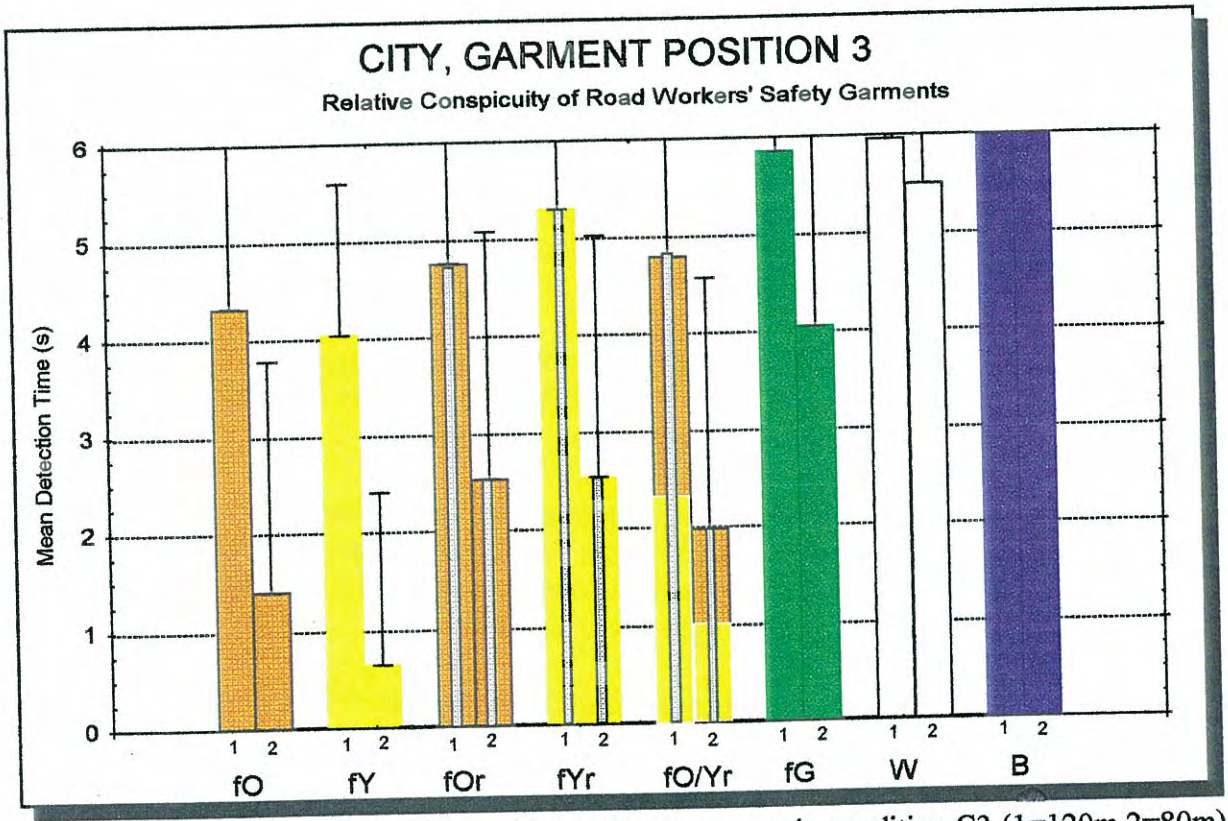

Figure 11b. Mean detection time (SD=⊤)for each test-garment in condition C3 (1=120m,2=80m)

showed the same order and the blue garment was never detected during these trials either.

The following statistics include only the 120m trials. A one-way ANOVA on the detection times revealed that there was an overall effect of the test-garment colours on the detection times, $F(7,88)= 4.65$, $p<001$. Post-hoc tests (Table 5) revealed that fYr had a significant longer mean detection time than FY and that the fG, W and B garments had significant longer detection times than any of the other garments.

Table 5. Condition C3: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value (s), SD=standard deviation

	fO M=4.3 SD=1.6	fY M=4.0 SD=1.5	fOr M=4.7 SD=1.6	fYr M=5.3 SD=1.2	fO/Yr M=4.8 SD=1.5	fG M=5.8 SD=0.4	W M=5.9 SD=0.1	B M=6.0 SD=0
fO	--------							
fY	.561	-------						
fOr	.391	.152	-------					
fYr	.055	.013*	.281	-------				
fO/Yr	.354	.133	.945	.313	-------			
fG	.003**	.000**	.031*	.273	.037*	--------		
W	.001**	.000**	.019*	.193	.022*	.835	--------	
B	.001**	.000**	.016*	.171	.019*	.783	.947	--------

3.1.2.4 Rural background with test-garment in position 9 (condition R9)
Background condition R9 (Figure 12a) showed a dark and moderate complex rural scene. The road was wet and the sky was overcast. The road worker was on the far peripheral left side in position 9.

Figure 12b shows that when the roadworker was at 120m, the fluorescent yellow garments with reflective tape (fYr) and the fluorescent orange (fO) had the shortest detection times. They were followed by the orange/yellow combination garment with reflective stripes (fO/Yr) and the garment fluorescent yellow (fY). Next to be detected were fluorescent green (fG), white (W) and fluorescent orange with reflective stripes (fOr). The mean detection time for blue (B) was beyond the limit of six seconds. The response times for the 80 m trials showed the same order except that the fG garment had a shorter mean response time than the fO/Yr garment.

The following statistics include only the 120m trials. A one-way ANOVA on the dection times revealed that there was an overall effect of the colours on the detection times; $F(7,88)= 4.65$, $p<001$). Post-hoc tests (Table 6) revealed that the fO and fYr garments were detected much faster than most of the other garments. The fYr test-garment was more visible than the fOr garment.

Figure 12a. Condition R9: Rural background with test-garment in position 9.

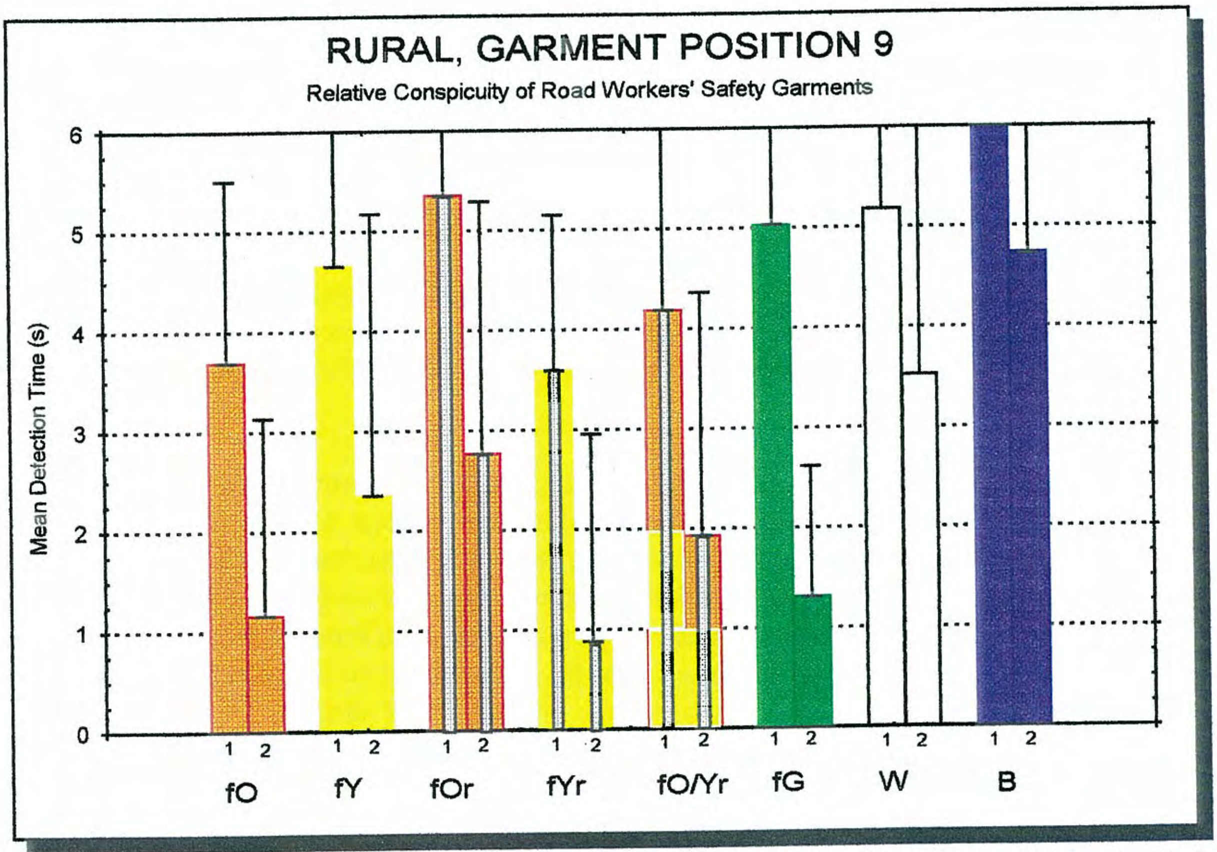

Figure 12b. Mean detection time (SD=⊤)for each test-garment in condition R9 (1=120m, 2=80m).

Table 6. Condition R9: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value(s), SD=standard deviation

	fO M=3.7 SD=1.8	fY M=4.6 SD=1.5	fOr M=5.3 SD=1.3	fYr M=3.5 SD=1.5	fO/Yr M=4.1 SD=1.8	fG M=5.0 SD=1.4	W M=5.1 SD=1.4	B M=6.0 SD=0
fO	-------							
fY	.116	-------						
fOr	.007**	.251	-------					
fYr	.859	.081	.004**	-------				
fO/Yr	.414	.445	.058*	.321	-------			
fG	.030*	.535	.595	.019*	.168	--------		
W	.016*	.387	.775	.010**	.105	.806	--------	
B	.000**	.029*	.289	.000**	.004**	.113	.179	--------

3.1.2.5 City background with test-garment in position 10 (condition C10)

Background condition C10 (Figure 13a) showed a grey and moderate complex city scene, near an intersection. The road was wet and the sky was overcast. The road worker was on the left half top side in position 10.

In this situation with the roadworker at 120m, the fluorescent orange garment (fO) had the shortest detection time (Figure 13b), followed by fluorescent green (fG), the orange/yellow combination garment with reflective stripes (fO/Yr), fluorescent yellow (fY) and fluorescent orange with reflective stripes (fOr). With clearly longer detection times the white garment (W) followed, then fluorescent yellow with reflective stripes (fYr) and again blue (B) was the test-garment colour with the longest mean detection time. The mean response times for the 80m trials were too short to enable a conclusive analysis.

A one-way ANOVA on the dection times revealed that there was an overall effect of the test-garment colours on the detection times; F(7/88)= 4.65, p<001. Post-hoc comparisons (Table 7) revealed that fYr was significantly less visible than all other garment colours except W and B.

Figure 13a. Condition C10: City background with test-garment in position 10.

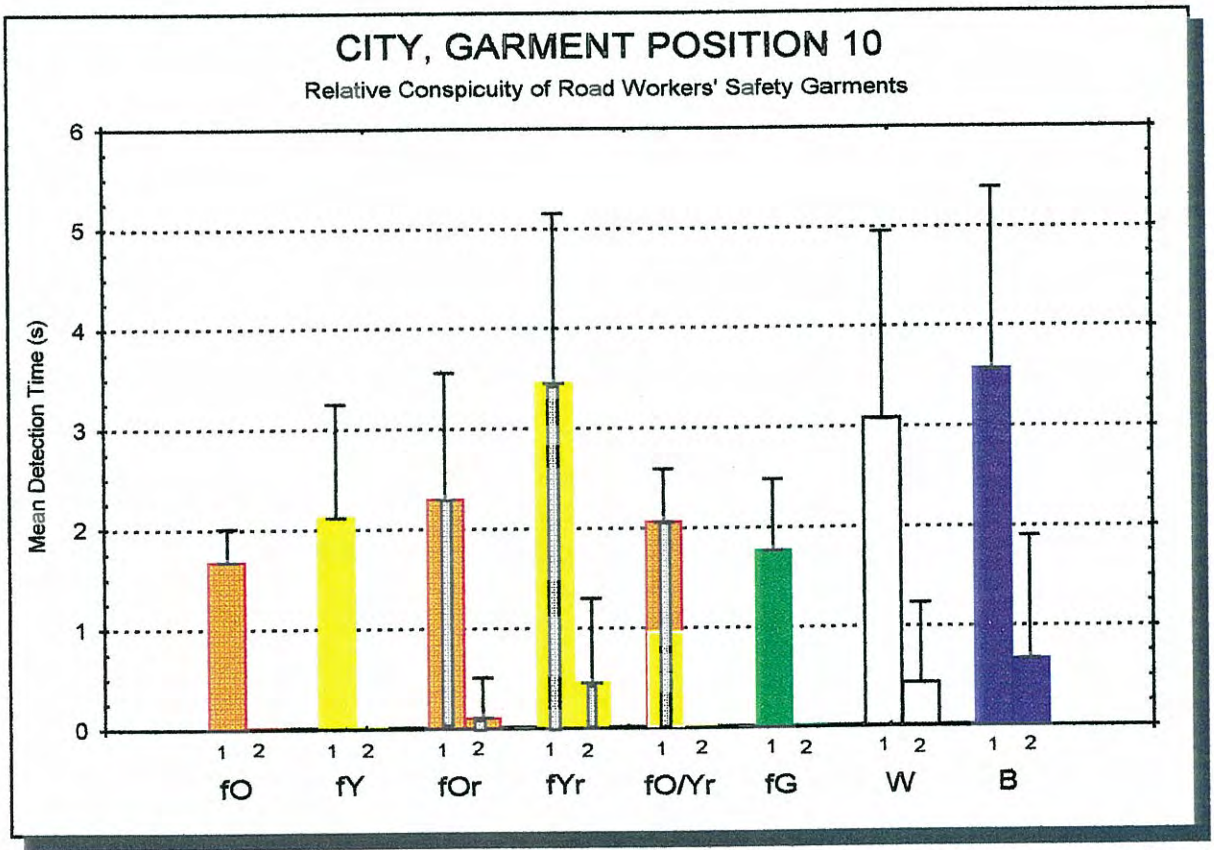

Figure 13b. Mean detection time (SD=⊤) for each garment in condition C10 (1=120m, 2=80m)

Table 7. Condition C10: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value(s), SD=standard deviation

	fO M=1.6 SD=0.3	fY M=2.1 SD=1.1	fOr M=2.3 SD=1.2	fYr M=3.4 SD=1.7	fO/Yr M=2.0 SD=0.5	fG M=1.7 SD=0.7	W M=3.0 SD=1.8	B M=3.5 SD=1.8
fO	-------							
fY	.415	-------						
fOr	.485	.736	-------					
fYr	.001**	.014*	.033*	-------				
fO/Yr	.485	.907	.650	.010**	-------			
fG	.869	.515	.324	.022*	.593	--------		
W	.010**	.074	.146	.491	.058	.016*	--------	
B	.000**	.007**	.018*	.811	.005**	.001**	.354	--------

3.1.2.6 Rural background with test-garment in position 11 (condition R11)

Condition R11 (Figure 14a) showed a moderate complex semi-rural scene on a straight road with many white road markings. The sky was overcast. The road worker was on the left half top side in position 11. As Figure 14b shows for the 120m data, the fluorescent orange garment with reflective stripes (fOr) had the shortest detection time. Next followed fluorescent yellow (fY), white (W), fluorescent yellow with reflective stripes (fYr), fluorescent orange (fO), fluorescent green (fG) and the fluorescent yellow/orange combination garment with reflective stripes (fY/Or); all of them in a narrow range. Again, the blue (B) test-garment had a significantly lower mean detection time. The mean response times for the 80m trials were too short to allow a conclusive analysis.

A one-way ANOVA on the dection times revealed that there was an overall effect of the test-garment colours on the detection times; $F(7,88)= 4.65$, $p<001$. Post-hoc comparisons (Table 8) revealed that the combination fO/Yr garment had a longer detection time than the fOr with reflective stripes and that B had a significant longer detection time compared with the other garments colours.

Figure 14a. Condition R11: City background with test-garment in position 11.

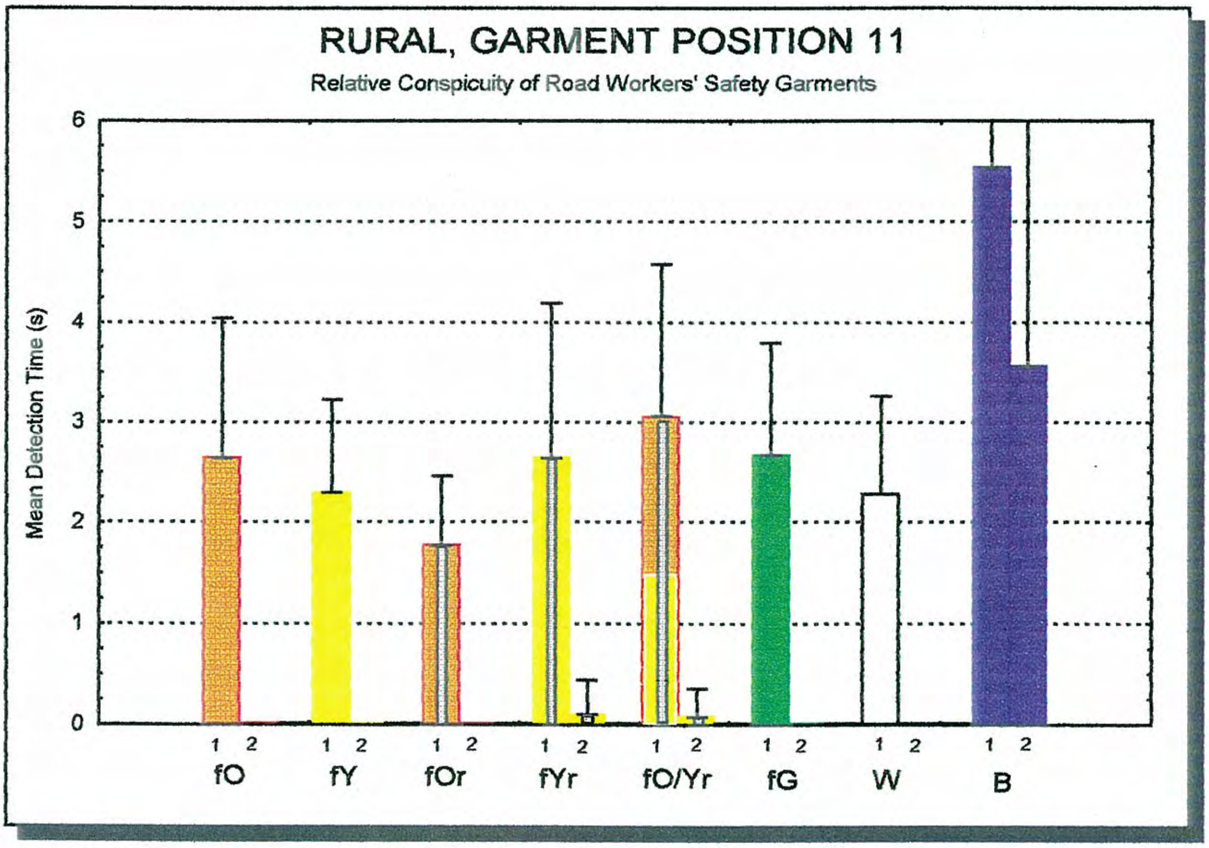

Figure 14b. Mean detection time (SD=т) for each garment in condition R11 (1=120m, 2=80m).

Table 8. Condition R11: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value, SD=standard deviation

	fO M=2.6 SD=1.3	fY M=2.2 SD=0.9	fOr M=1.7 SD=0.7	fYr M=2.6 SD=1.5	fO/Yr M=3.0 SD=1.5	fG M=2.6 SD=1.1	W M=2.2 SD=0.9	B M=5.5 SD=1.1
fO	-------							
fY	.468	-------						
fOr	.076	.288	-------					
fYr	.996	.471	.076	-------				
fO/Yr	.394	.117	.009**	.391	-------			
fG	.953	.433	.067	.948	.428	-------		
W	.458	.986	.295	.461	.113	.423	--------	
B	.000**	.000**	.000**	.000**	.000**	.000**	.000**	-------

3.1.2.7 Rural background with test-garment in position 12 (condition R12)
Background condition R12 (Figure 15a) showed a simple rural scene, on a straight road with a bend at the horizon. Bright orange cones were on the left side of the road. The sky was overcast. The road worker was shown at the top of the slide, on the left side of the road in position 12.

Figure 15b shows that all mean detection times were very short, with the time for the fluorescent green (fG) garment being the shortest. Next followed fluorescent yellow (fY), the same colour with reflective tape (fYr), fluorescent orange with reflective stripes (fOr), fluorescent orange (fO) and the orange/yellow combination garment with reflective stripes (fO/Yr). Blue (B) and white (W) had the longest detection times.The mean response times for the 80m trials were too short to allow a conclusive analysis.

A one-way ANOVA on the dection times revealed that there was an overall effect of the test-garment colours on the detection times; F(7,88)= 4.65, p<001. Post-hoc comparisons (Table 9) revealed that W and B had significantly longer mean detection times than any other garments except the fYOr garment.

Figure 15a. Condition R12: Rural background with test-garment in position 12.

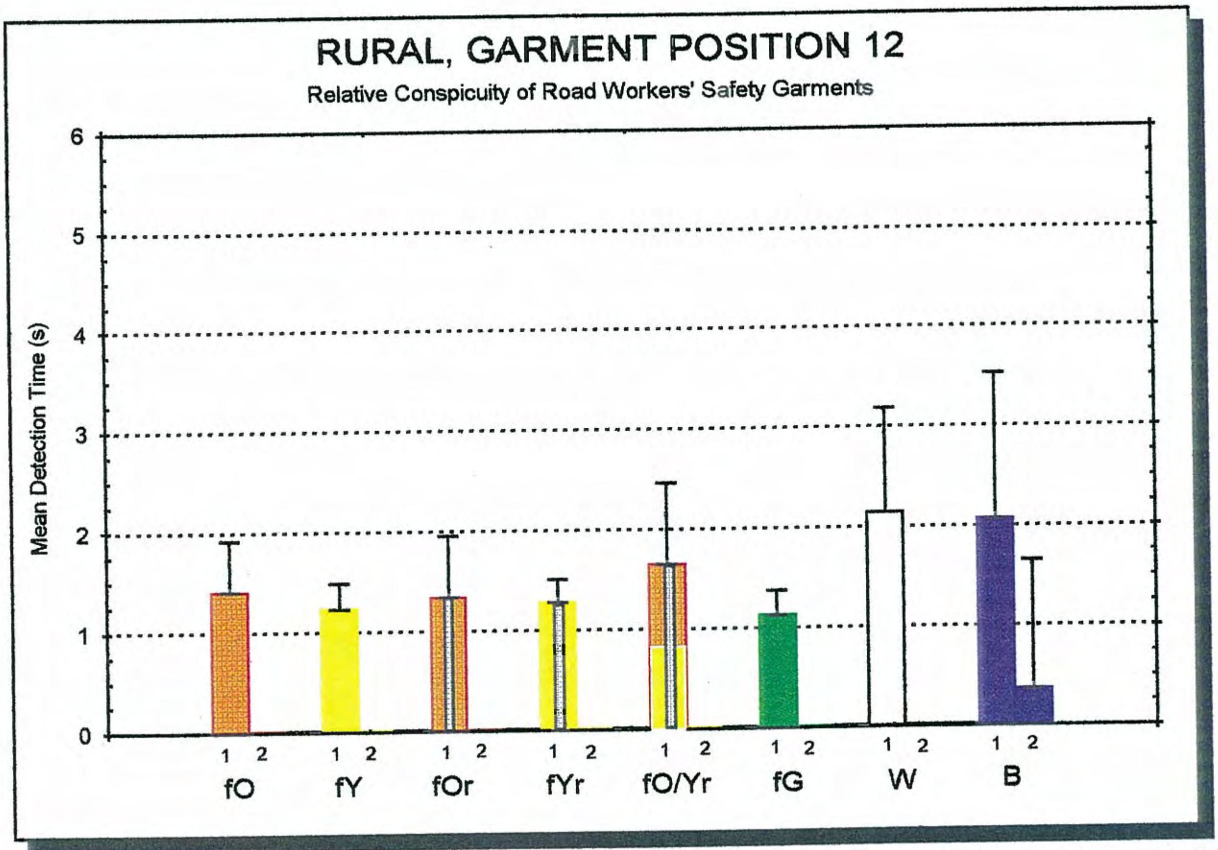

Figure 15b. Mean detection time (SD=⊤) for each garment in condition R12 (1=120m, 2=80m).

Table 9 Condition R12: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value(s), SD=standard deviation

	fO M=1.4 SD=0.5	fY M=1.2 SD=0.2	fOr M=1.3 SD=0.6	fYr M=1.2 SD=0.2	fO/Yr M=1.6 SD=0.8	fG M=1.1 SD=0.2	W M=2.1 SD=1.0	B M=2.0 SD=1.4
fO	-------							
fY	.563	-------						
fOr	.829	.717	-------					
fYr	.691	.856	.856	-------				
fO/Yr	.440	.179	.324	.244	-------			
fG	.371	.751	.497	.618	.098	--------		
W	.020*	.004**	.012*	.007**	.116	.002**	---------	
B	.037*	.008**	.022*	.013*	.181	.003**	.812	--------

3.1.2.8 City background with test-garment in position 13 (condition C13, centre).
Background condition C13 showed a complex city scene on a straight road with many white buildings. Bright orange cones were on the left side of the road (Figure16a). The sky was overcast. The road worker was shown in the centre of the slide in position 13 in front of a white building.

Figure 16b shows that the fluorescent orange garment was detected fastest (fO), followed closely by the fluorescent green (fG), fluorescent orange with reflective stripes (fOr), fluorescent yellow with reflective stripes (fYr) and fluorescent yellow (fY). The blue (B) and the white (W) garments were expected to be seen last, but the fluorescent orange/yellow combination test-garment with reflective stripes (fO/Yr) had an even longer mean detection time. The mean response times for the 80m trials were too short to allow a conclusive analysis.

A one-way ANOVA on the dection times revealed that there was an overall effect of the test-garment colours on the detection times; $F(7,88)= 4.65$, $p<001$. Post-hoc comparisons (Table 10) revealed that the fO/Yr and the W garments had significant longer mean detection times than most of the other garments.

Figure 16a. Condition C13: City background with test-garment in position 13 (centre).

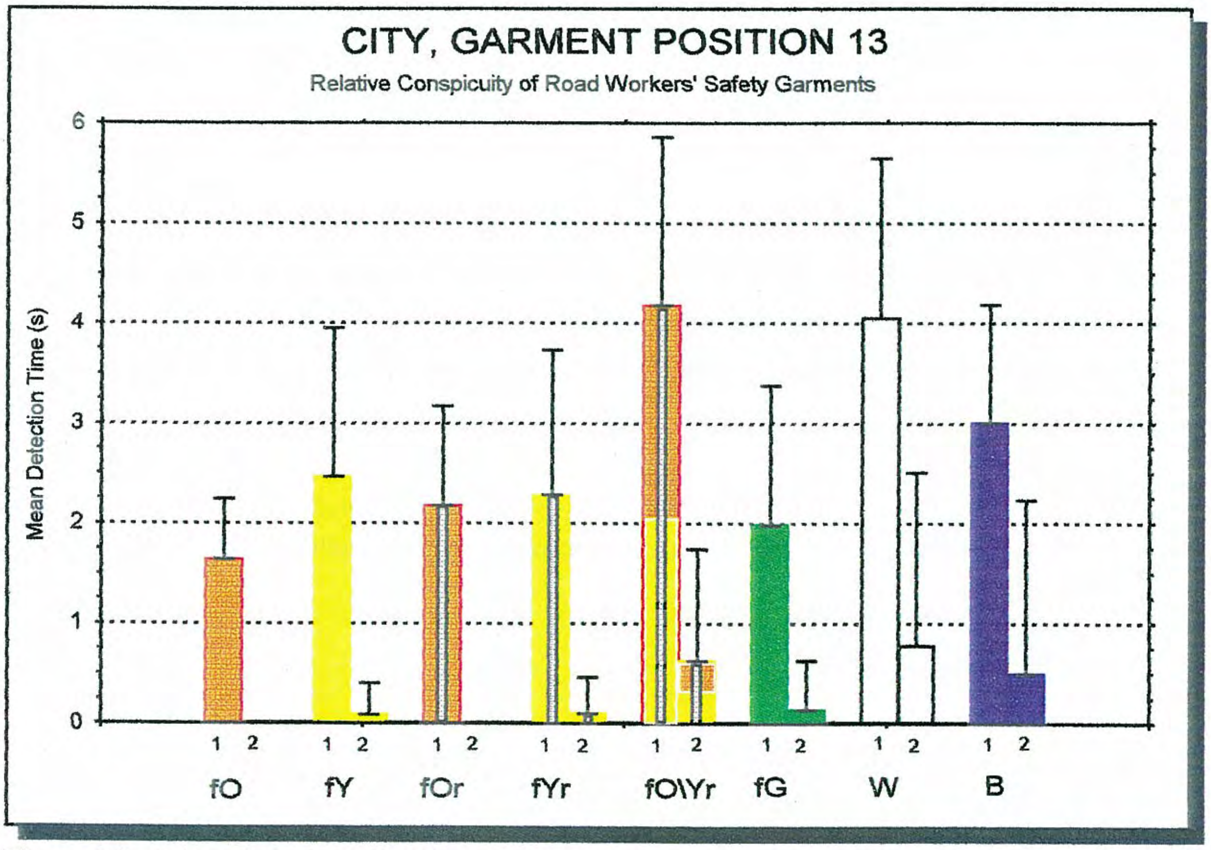

Figure 16b. Mean detection time (SD=┬) for each garment in condition C13 (1=120m, 2=80m).

Table 10. Condition C13: comparisons of the test-garment detection times; marked differences are significant: *=p<0.05; **=p<0.01; M=mean value(s), SD=standard deviation

	fO M=1.6 SD=0.5	fY M=2.4 SD=1.5	fOr M=2.1 SD=1.0	fYr M=2.2 SD=1.4	fO/Yr M=4.1 SD=1.6	fG M=1.9 SD=1.4	W M=4.0 SD=1.6	B M=3.0 SD=1.1
fO	-------							
fY	.142	-------						
fOr	.343	.598	-------					
fYr	.247	.752	.832	-------				
fO/Yr	.000**	.002**	.000**	.001**	-------			
fG	.544	.384	.731	.579	.000**	--------		
W	.000**	.005**	.001**	.002**	.808	.000**	--------	
B	.014*	.314	.127	.187	.036*	.063	.063	--------

3.1.3 The Effects of Rural and City Backgrounds

The test-garments were tested either against city (4 slides) or rural backgrounds (4 slides). Figure 17 shows the overall effect of these backgrounds on the visibility of all garments combined. Visual inspection of the graph reveals that overall the test-garments were detected faster against the rural backgrounds (M=2.8s, SD=1.8) than against the city backgrounds (M=3.3s, SD=1.8). An analysis of variance (ANOVA) confirmed a significant shorter overall mean detection time for garments shown against the rural backrounds, $F(1,766)=1.06$; $p<0.01$, than shown against the city backgrounds.

Figure 18 shows the effects of the city and rural backgrounds on the mean detection time for each of the eight test-garments. The graph shows that the background played a large role for the less visible garments - fluorescent yellow and orange with reflective stripes (fYr,fOr), the fluorescent orange/yellow garment with reflective stripes (fO/Yr), the fluorescent green (fG), white (W) and blue (B). All these garments had shorter mean detection times against the rural background than against the city background. The background did not affect the visibilty for the most visible garments fluorescent orange (fO), fluorescent yellow (fY) and fluorescent orange with reflective stripes (fOr).

Significant background effects (ANOVAs) were received for the fluorescent yellow garment with reflective stripes, $F(1,94)=9.38$, $p<0.01$, and the white garment, $F(1,94)=11.5$, $p<0.01$.

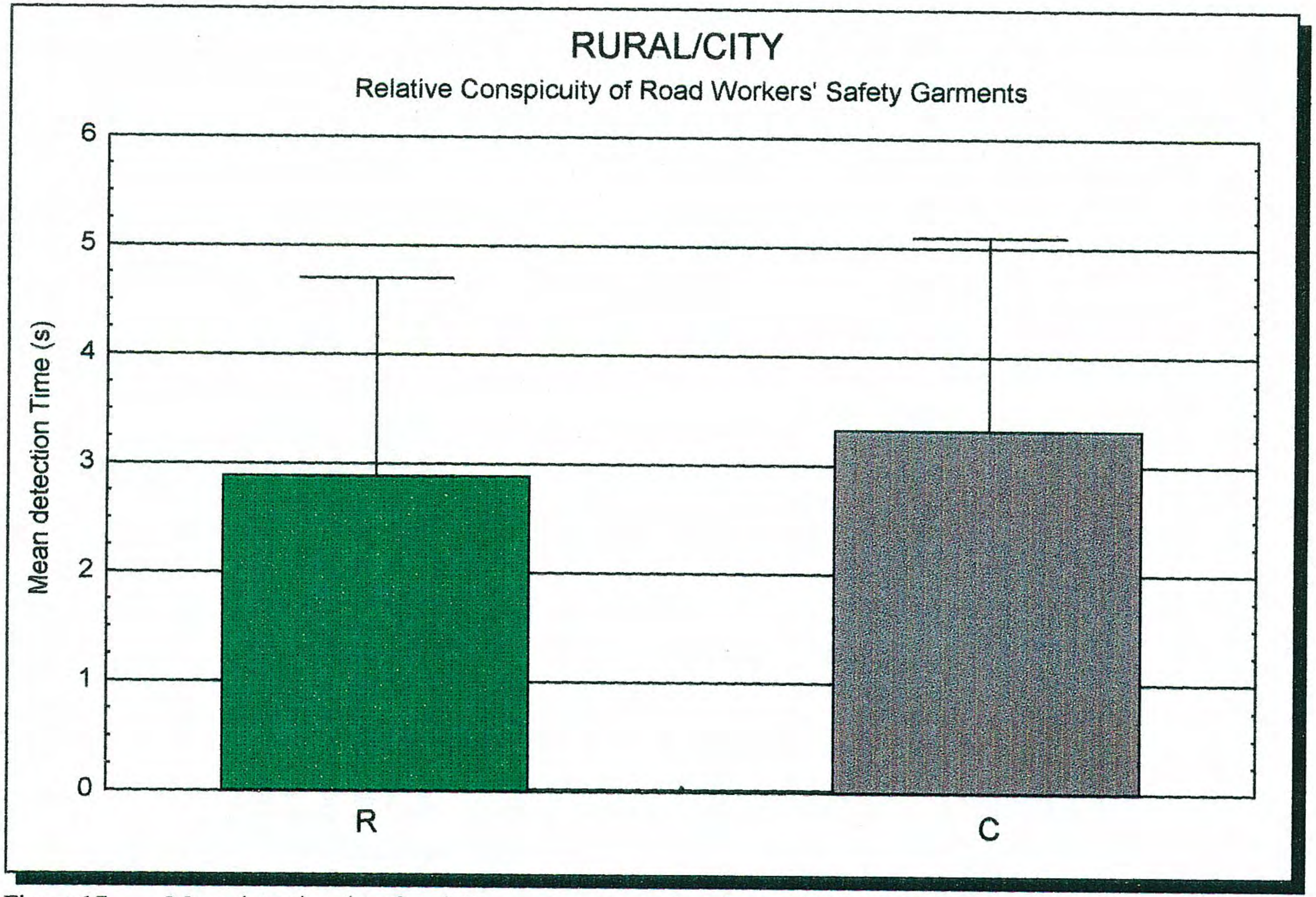

Figure 17. Mean detection time for all 8 test-garments against the rural (R) and city (C) backgrounds.

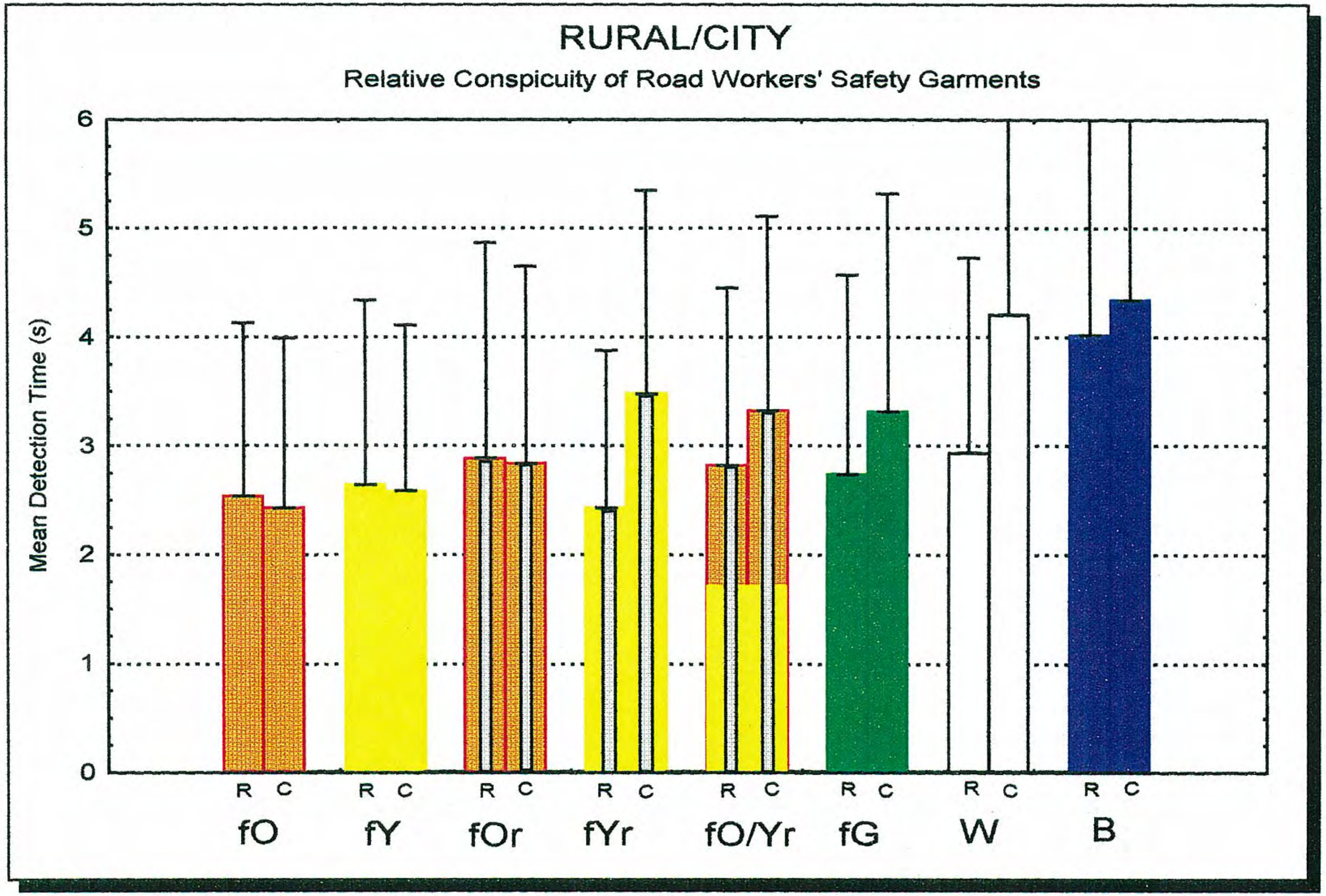

Figure 18. Mean detection time for each test-garment shown against rural (R) and city (C) backgrounds.

3.1.4 The Effects of Test-Garment Positions and Tracking Time Error

This analysis concerned the effect of the 8 test-garment positions on the detection times for the garments (Figure 19). The figure reveals that the mean detection times were dependent on where the road-workers were positioned on the slides. It took the participants the longest time to detect the road workers at the position 9 and 3 (on the left and right side on the slides). The shortest detection time were scored when the road worker was at position 12 (at the top of the slide projection).

A one-way ANOVA on the detection times revealed a significant overall effect of the garment positions on detection times; $F(7,760)=63.39$, $p<0.01$. Post-hoc analysis showed that the times for detecting the road workers at the positions 3 and 9 were significantly longer, and shorter for road workers at position 12, than for any other positions.

The shortest mean tracking error time was received for the slides with the road worker in position 3, followed by roadworkers in position 12,13 (centre), 10,11,9, and 1. A one-way ANOVA on the dependent variable central task error time revealed no signifcant effect of the roadworkers' position ($p>0.05$).

Finally, analysis of the main study tested whether there was a relationship between individual detection times and central task error times. The scatterplot on Figure 20 does not show a correlation between these two variables. The majority of data points revealed detection times of less than 2.5 seconds and a tracking task error time of less than 2 seconds. The regression line in Figure 20 shows a slope, $r=-0.028$, which does not indicate a significant relationship between detection times and central task error performances ($p>0.05$).

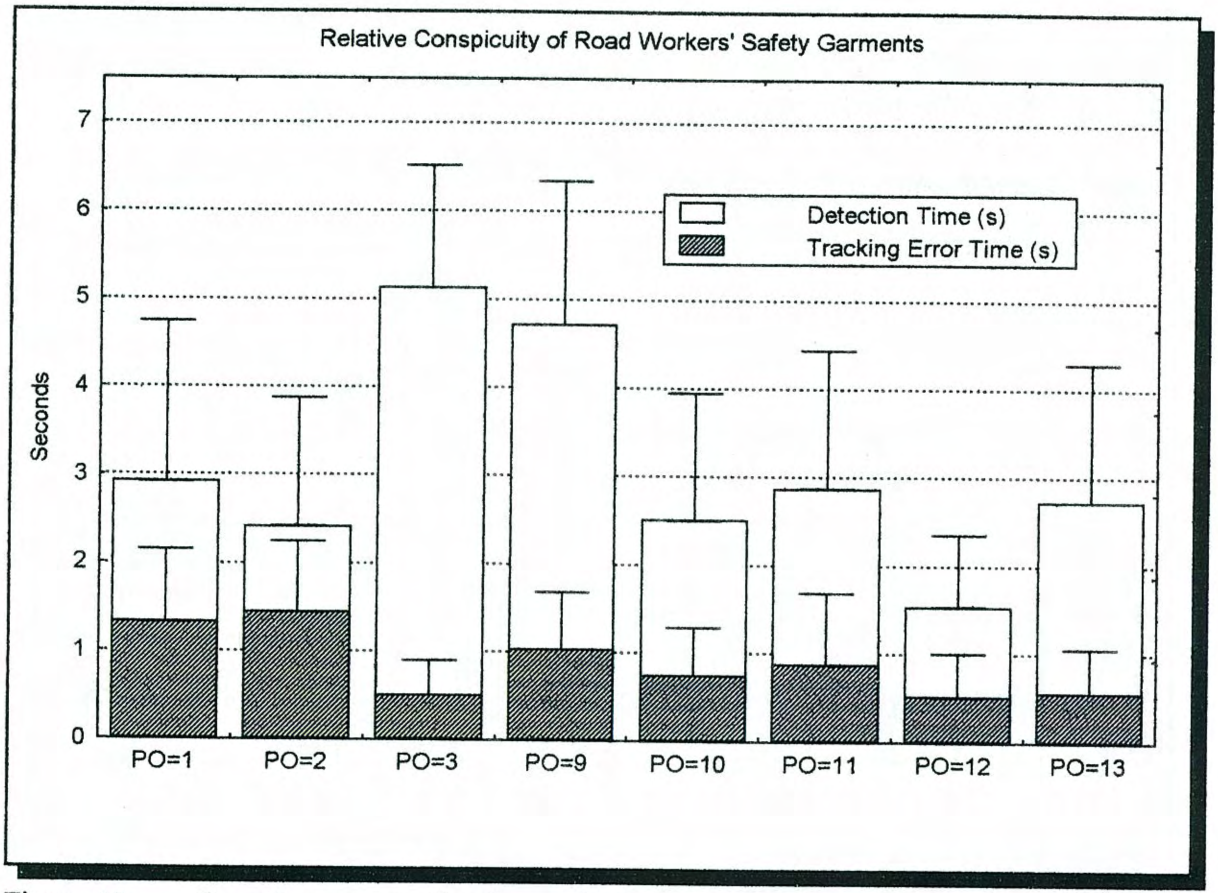

Figure 19. Overall mean detection time and mean central task tracking error time for each of the eight test-garment positions (PO=position).

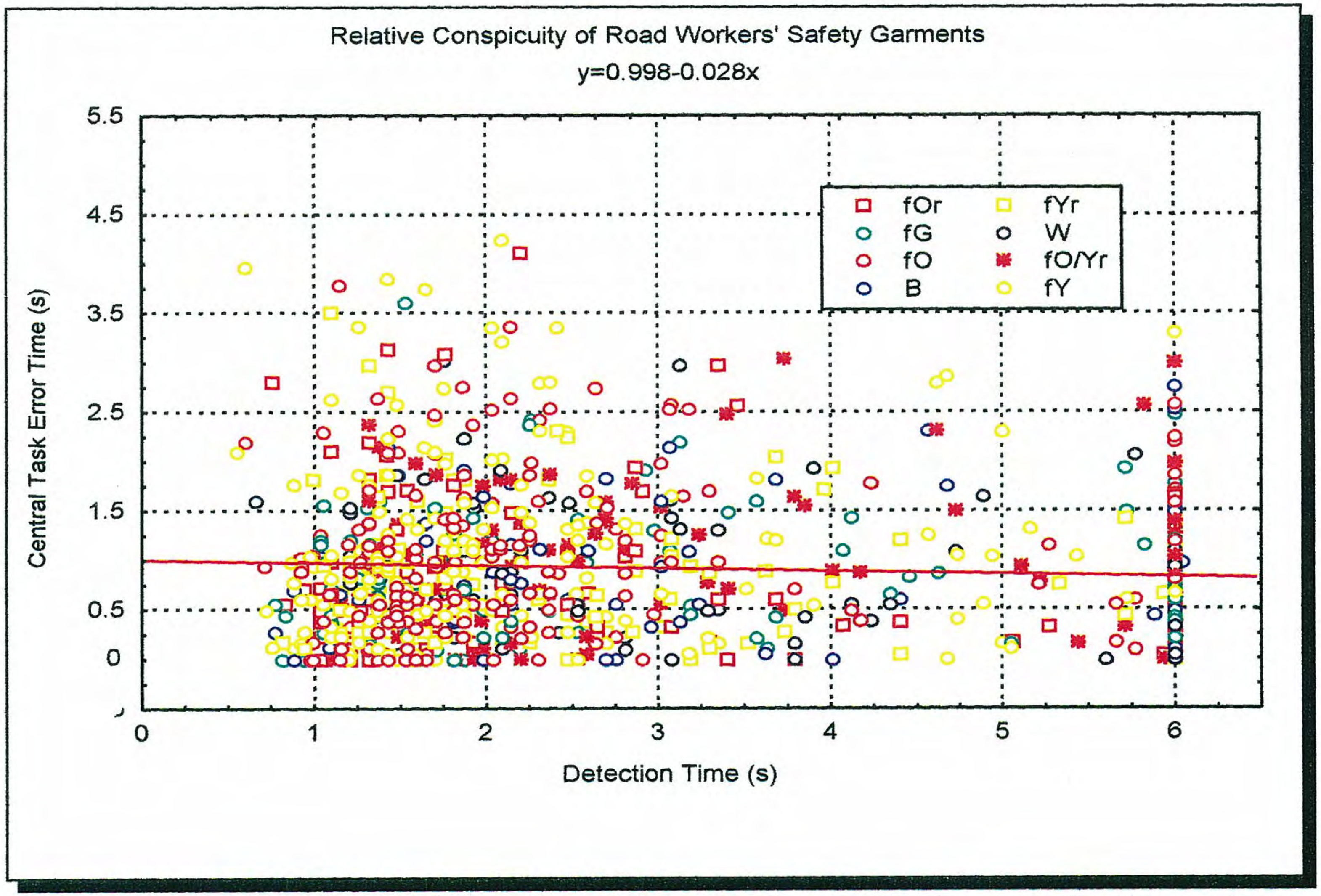

Figure 20. Scatterplot for detection times and central task error time for the eight test-garments: fOr=fluorescent orange with reflective stripes, fG=fluorescent green, fO=fluorescent orange, B=blue, fYr=fluorescent yellow with reflective stripes, W=white, fO/Yr= fluorescent orange/yellow with reflective stripes, fY= fluorescent yellow.

3.2 Results of the First Follow-Up Study

The first follow-up study used two groups of 12 participants who performed the same experimental procedure as the participants in the main study except that they had to detect a roadworker who was wearing always the same test-garment ('search conspicuity task', see Section 1, p.19, Introduction) against all different road scenes.

3.2.1 Overall Effect of Search Conspicuity

The first group of participants in this study were told that they were required to detect in each test-slide (with the same road scenes as in main experiment) a road worker always wearing a fluorescent orange (fO) garment. The second group of participants followed the same procedure except these participants had to detect a roadworker always wearing a fluorescent yellow (fY) garment.

Figure 21 shows the mean detection time of these 'search conspicuity' (=**SC**) trials for the 120 metres viewing distance and combined for all background conditions. The two mean detection values (fO and fY) for these trials were compared with the values of the 'attention conspicuity' trials. In the 'attention conspicuity' (=**AC**) trials the particiants did not know the colour of the garments they had to detect and the analysis included only two trials from each participants in the main experiment where they had to detect the roadworkers wearing the fO (96 trials) or the fY garments (96 trials).

Figure 21 shows that the garments were detected faster when their colour was known to the participants. For the fO garment, the mean detection time for the AC trials was M=2.5s, SD=1.5, compared to the value for the SC trials with M=1.8s, SD=1.2. For the fY garment, the mean detection time for the AC trials was M=2.5s, SD=1.5, compared with M=2.1s, SD=1.2, for the SC trials.

Two one-way ANOVAs on detection times for the two conditions (SC trials against AC trials) and the two garments showed that the participants detected the orange garment significantly faster if they knew the colour; $F(1,190)=14.58$, $p<0.01$. For the yellow garment the difference between the mean detection times of SC trials and AC trials did not quite reach statistical significant on the $p<0.05$ level with $F(1,190)= 2.81$, $p=0.09$.

3.3 Results of the Second Follow-Up Study

In this prelimanary second follow-up study two groups of 5 participants were tested. The first group were participants who were identified as 'colour vision impaired'. Four of the participants had a mild and one participant a severe 'red-green defect' (deuteranope). They performed the same procedure as the first group of participants in the main experiment except that the blue test-garment was replaced with a fluorescent red test-garment. Red is a colour that detotronopes normally have difficulty to perceive. The second group were participants with normal colour vision and they served as a control group. The participants of the control group were fitted with an eye-tracker so that their eye movements could be analysed while they did the experimental procedure.

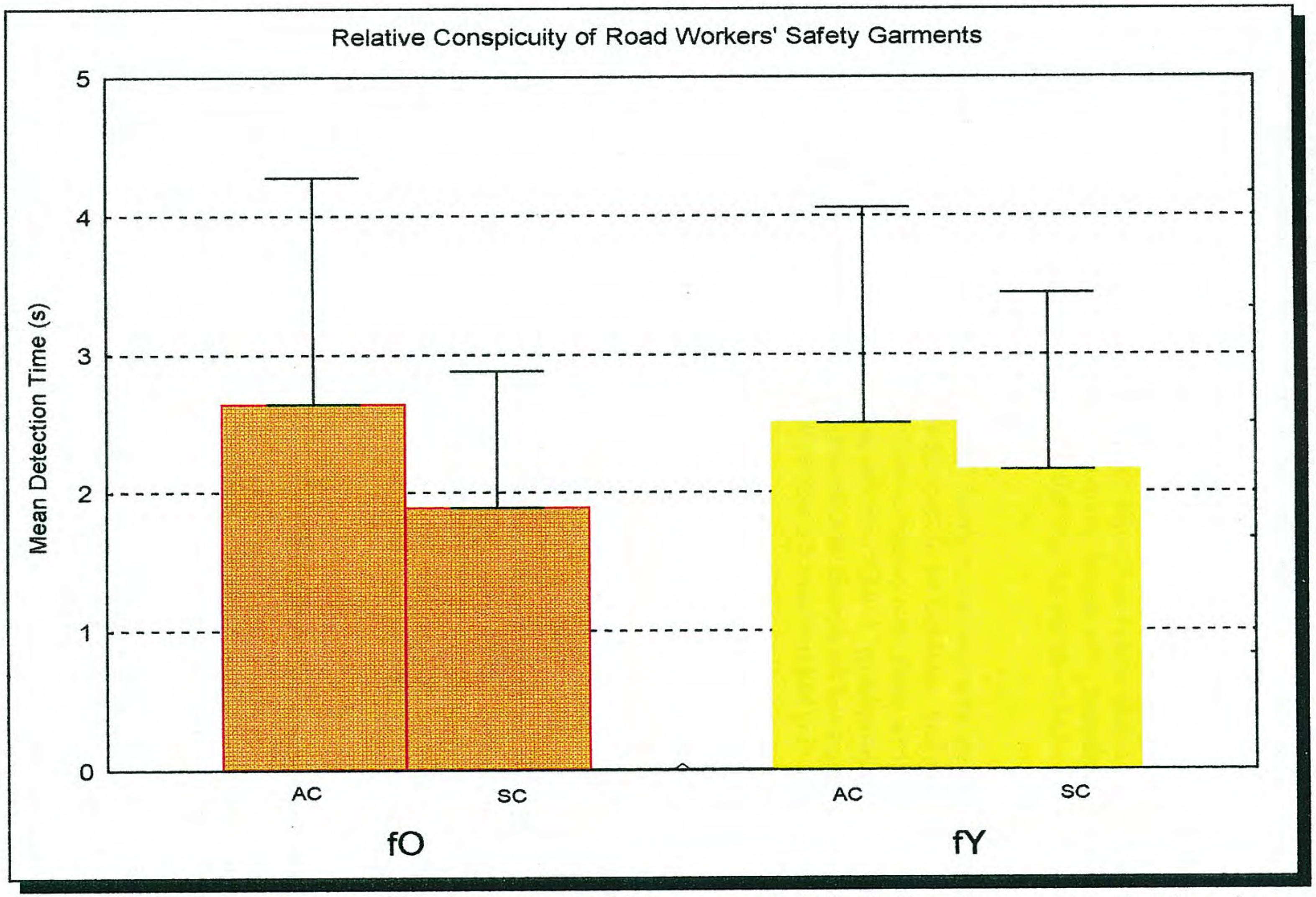

Figure 21. The effects of attention conspicuity (AC) and search conspicuity (SC) on the mean detection times for fluoresent orange (fO) and fluorescent yellow (fY).

3.3.1 Impaired colour vision and relative conspicuity

Figure 22 shows that the participant with impaired colour vison had longer mean detection times for the fluoresecent red (fR), fluorescent orange (fO), fluorescent yellow (fY), and fluorescent green (fG). However, separate ANOVA's performed on each pair of detection times (normal vision against impaired colour vision) revealed no significant difference between any of the pairs' detection times (all ps>0.05).

3.3.2 Results from the eye tracker trials

The five control participants from the second follow-up study were fitted with an eye tracker so that their eye scanning pattern could be observed while they were performing the central tracking task and the peripheral detection task. The video recordings showed that all participants spent most of the time fixating the central task using only little time to explore the peripheral regions of the road scenes. As soon as the colour of the roadworker's garment attracted their attention, they moved their eyes to the place where they suspected the roadworkers. If their eye scanning proved unsuccessful (road worker was not at the suspected place) participants immediately moved their eyes back to the central task.

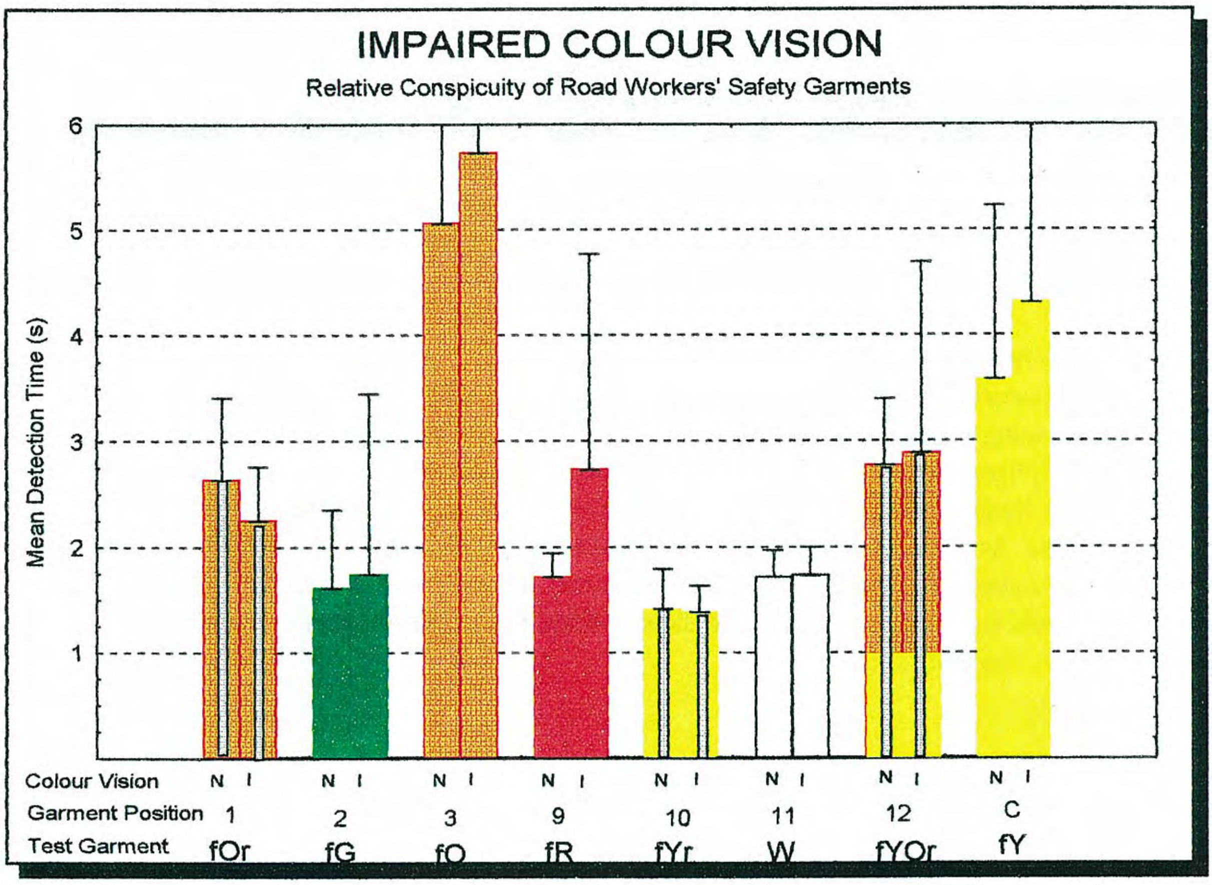

Figure 22. Mean detection time in seconds for each test-garment in different positions for participants with impaired colour vision (I) and normal vision (N).

4. DISCUSSION

The main study of this research programme tested the relative conspicuity of eight different test-garments against eight different backgrounds (four rural and four city). The colours of the garments were not known to the participants and therefore the task involved attention conspicuity (see Section 1 Introduction). Additionally, a first follow-up study tested detection times for test-garments which were known to the participants (search conspicuity task). The second follow-up study assessed the performance of five colour vision impaired participants and analysed the scanning behaviour of control participants (with normal vision) performing the central tracking and peripheral detection task.

4.1 The Fluorescent Orange and Yellow were Equally Conspicuous

Results of the main study indicated that overall the fluorescent orange and the fluorescent yellow were more visible than any of the other test-garments. Overall mean detection time for the fluorescent orange was slightly shorter than for the fluorescent yellow garment, but the difference was not statistically significant. Also, there was no significant difference between the detection times of these garments against any of the eight different backgrounds.

The result that fluorescent orange was not significantly more visible than fluorescent yellow is not consistent with the results of some of the studies reviewed in Section 1.3.4 (Introduction). Michon et al. (1969) found that orange was clearly the most visible garment, however, this result should be regarded with caution for several reasons.

They evaluated the conspicuity of safety garments measuring their visibility distance (scaled down), i.e., the longest distance at which the safety garment worn by a road worker may still be detected. They used small coloured paper chips (1:60 of the size of real garments) and extrapolated from data of two participants that fluorescent orange had a visibility distance of 4.3 km while fluorescent yellow had only a distance of 1.5km. It is questionable whether such measures of conspicuity have any validity in predicting the conspicuity of the garments in shorter ranges relevant for road safety.

In a second experiment they unfortunately excluded the fluorescent yellow so comparisons between fluorescent orange and yellow were not possible. For a third experiment, they used employees from the Ministry of Transport and related services as research participants and this may have influenced the findings. As employees in this field are often exposed to safety clothing, the detection rate of familiar coloured safety garments may have been positively biased. This has been demonstrated in research showing the influence of expectancy (Shinar, 1985) and higher detection rates for search conspicuity tasks (Cole & Hughes, 1984).

Finally, as stated by a number of researchers (e.g., Boersema & Zwaga, 1985; Boersema, Zwaga, & Adams, 1989; Cole & Hughes, 1984; Cole & Jenkins, 1984) the conspicuity of a target object is affected by the physical properties of that object and by the background against which it is displayed. Because of the relative simple backgrounds used by Michon et al. (1969) their findings may not be relevant when the complex backgrounds of real-world situations are considered.

Bradford et al. (1992) found fluorescent yellow and white to be most conspicuous. Background influence was again highlighted in this study as findings indicated that contrast on the garment itself (black and fluorescent yellow) did not increase conspicuity. Rather, conspicuity was influenced by the contrast between the test shirt and the background as neither fluorescent yellow nor whites occur naturally in a pine forest environment. However, fluorescent orange, which does not occur naturally in this environment either, was considerably less visible, which is not consistent with the results from Michon et al. (1969) or this current study. Again, the background is different to the complex background encountered by drivers, and this may have influenced the results.

A recent field study conducted by Januszke and Simpson-Lyttle (1996) found no clear conspicuity difference between fluorescent green, yellow-green, yellow and red/orange close weave safety garments. These authors considered the yellow-green open weave vest and the close weave red-orange jacket offered the best combination of conspicuity and resistance of fading. However, the experimental procedure used raises a number of concerns.

First, the road workers were positioned in a curve like fashion. Not surprisingly, a large position effect was evident - in almost 40% of all the trials the observers choose the worker in position one, which was the closest. Further, it would be difficult, if not impossible, to decide which worker was seen first if they all appeared in the visual field at the same time. Decisions could be influenced by observers' response bias. No statistics were provided.

Second, three observers were in the rear seat of the vehicle. They changed positions to occupy each seat position. Clearly, passenger observations from the rear seat of a vehicle are not equivalent with a driver in the front seat, performing the dual task of driving and scanning the road to locate road workers.

4.2 Test-Garments were Detected Faster if their Colour was Known

An important result of the first follow-up study was that the detection time for the fluorescent orange garment was significantly shorter when participants knew the colour (search conspicuity trials) compared to trials when they did not (attention conspicuity trials). For the yellow garment search conspicuity trials also resulted in a shorter mean detection time compared to attention conspicuity trials. This difference, however, did not quite reach statistical significance. Firm conclusions cannot be drawn from this finding alone, however, as a number of factors may have influenced this result.

The literature offers a theoretical basis for search conspicuity detection times being shorter. First, it has been shown that pre-knowledge influences conspicuity (e.g., Biederman, Glass & Stacy, 1973; Loftus & Mackworth, 1978). Second, Cole and Jenkins (1984) clearly demonstrated that detection rates during search conspicuity trials (observer has prior information) were greatly improved when compared with attention conspicuity trials (observer has no prior information). Third, Shinar (1985) recommended standardised, distinguishable, and recognisable tags be worn by nighttime pedestrians and cyclists as results of his study showed expectancy significantly increased recognition. Finally, Green and Anderson (1956) and Smith (1962) demonstrated search times were considerably shorter when the colour of the target was known.

Although it was expected that detection times would be shorter if the colour was known, it was not expected that the difference would be significantly different for the fluorescent orange and not for the yellow. As the eye is most sensitive to light which appears yellow-green (see Introduction Section 1.4.1, Figure 1) in daylight levels of light intensity, it could generally be expected that fluorescent yellow would be more conspicuous. As yellow has one of the largest colour zones (see Introduction Section 1.4.2, Figure 3), again, it would be expected that yellow would be more readily detected than orange.

In addition, it could also be expected that fluorescent yellow would be more conspicuous in the periphery as rods have brightness sensitivity, not colour sensitivity. However, when the road worker was positioned at 3 (Condition C3), detection times were shorter for fluorescent yellow, whereas detection times were shorter for the fluorescent orange, when the road worker was positioned at 9 o'clock.

The fluorescent orange was more conspicuous against bright backgrounds. This was particularly evident when the immediate background was a white building in the city condition (C13). Conversely, the fluorescent yellow was more conspicuous against some dark backgrounds in both the city and rural scenes (e.g., R2, C3, R11). This is consistent with Bradford et al. (1992) who also found fluorescent yellow considerably more visible than fluorescent orange against a dark background. Other studies using real-life settings have also found the greater the degree of physical difference between the target and background items, the more conspicuous the target is (e.g., Jenkins, 1982, cited in Cole & Hughes, 1984; Stager & Hameluck, 1986, cited in Donder, 1994).

The orange cones used in the road scenes may have been cues for observers as road workers could be expected to be located in that vicinity. Alternatively, the orange cones may have been a distraction as detection times were shorter for the fluorescent yellow when the road worker was positioned directly behind a cone (see condition C1). This result is supported by previous laboratory studies which have shown search efficiency increased as the similarity between targets and nontargets decreased (Duncan & Humphreys, 1989) and increased local colour contrast between target objects and background improved detection rates (Nothdurft, 1993).

Although it was clearly demonstrated that knowledge of the colour of the safety garment improved detection times, there can be no firm conclusions as to whether fluorescent orange or yellow would be the better colour to use if safety garments were to be standardised. It is considered that further systematic trials would need to be carried out using these two colours against a number of different backgrounds, in different weather conditions, to determine which of the two would consistently be the most conspicuous.

In addition to the above considerations, the importance of verifying the most conspicuous colour in different weather conditions is highlighted in Zurich, Switzerland, where the use of safety garments has been standardised, and only fluorescent orange, is used as fluorescent yellow is not as clearly conspicuous in fog conditions ('Strassenverkehrsamt Zuerich, Switzerland, personal communication, 1995).

4.3 Reflective Stripes on Garments Impaired their Conspicuity

Overall, the fluorescent orange and fluorescent yellow garments with reflective stripes were less visible compared to the garments of the same colour but without such stripes. This was particularly noticeable against brighter backgrounds. For example, yellow with reflective stripes was much less conspicuous than the yellow without stripes in three of the four cities conditions with brighter backgrounds. The reflective stripes appeared to make the fluorescent yellow to lose its colour becoming greyish yellow which blended easily in a bright background.

Although it has been shown that colour is relevant in visual conspicuity (e.g., Backs & Walrath, 1992; Treisman & Gelade, 1980; Williams, 1980), this result is consistent with studies that have shown that luminance and colour contrast between target and background are more important than luminance per se (Bradford et al., 1992; Duncan & Humphreys, 1989; Jenkins, 1982, cited in Cole & Hughes, 1984; Nothdurft, 1993; Stager & Hameluck, 1986, cited in Donderi, 1994).

The fluorescent orange with reflective stripes was also much less conspicuous than the orange without stripes, even against the darker rural backgrounds (e.g., R2 and R9). These results indicate that reflective stripes should not be used on safety garments worn in daylight conditions as conspicuity is reduced.

4.4 The Combination Garment fluorescent Orange/Yellow

Overall, detection times for the combined orange and yellow garment with reflective stripes were longer than for the fluorescent yellow or orange garments either with or without reflective stripes. There was, however, no consistent pattern of responding. This garment was less visible than either the yellow with reflective stripes or orange with reflective stripes in conditions where the background was cluttered (e.g., R11, R12, C13), but had a shorter detection times when the background was less cluttered in one condition (C10). However, results for both cluttered and uncluttered conditions were variable. For example, in two uncluttered conditions (C2, R9) detection times were shorter than the fluorescent orange, and longer than the fluorescent yellow. Against a bright background (C13) the combination garment was less conspicuous than any of the other garments. Although the reasons for the slower and variable detection times for this garment are not immediately apparent, a possible explanation may be the smaller area of each colour, as Johnson (1986) reports colours of larger stimuli can be discriminated farther out on the peripheral retina. This is not consistent with laboratory research conducted by Jenkins and Cole (1982) who found luminance of target discs influenced conspicuity whereas size of a target disc did not. However, results from laboratory conditions may not generalise to real-life situations.

It may be that from a distance, the two colours are less distinct, and blend to be seen as one colour that is less bright than each colour individually, and become less visible against both dark and bright backgrounds. Alternatively, the combination coloured shirt may not be associated with road workers. Clearly, the reflective stripes did not improve conspicuity, but it may be useful to compare the two-colour garment without reflective stripes, with the single coloured garments fluorescent orange and yellow.

This result, however, is consistent with Bradford et al. (1992) who also found the single colour garments (fluorescent yellow and white) were detected more readily than combination garments (fluorescent orange with a yellow band, red and green, black with two fluorescent yellow 'v's).

4.5 The Fluorescent Green Test-Garment

Overall results showed the fluorescent green had slower detection times than the fluorescent orange, yellow, and the fluorescent orange and yellow with reflective stripes. Although the fluorescent green was surprisingly conspicuous against many backgrounds, results were inconsistent. For example, detection times were considerably slower for fluorescent green than either fluorescent yellow or orange in both city and rural conditions where the background appeared dark (C3, R9), and also against a brighter background (C1). On the other hand, against a dark rural background (R2), detection times for the fluorescent green garment was shorter than for the fluorescent orange garment, but longer than the fluorescent yellow one. This result was reversed against more cluttered backgrounds (R11, C13). In one condition (R12) detection times for the fluorescent green garment was shorter than for all other colours. However, detection times for all colours was shorter for this condition (12 o'clock) than any other, and the result for fluorescent green was not significantly different from either the fluorescent yellow or orange. Variable detection times for fluorescent green were also found by Januszke and Simpson-Lyttle (1996) who reported fluorescent green as highly conspicuous in some trials, but unsatisfactory in others.

If the spectral curve sensitivity alone is considered (Figure 1), green could be expected to be a highly visible colour. However, as sensitivity to green light diminishes more rapidly than other colours (Figure 3), combined with the inconsistent results obtained, it would not be recommended that a green safety garment be used.

4.6 The White and Blue Test-Garments

The least visible garments were clearly the brightest (white) and the darkest (blue). They had the longest detection times for most of the backgrounds. White was clearly less visible in the city compared to the rural background due to the white markings or white buildings.

Blue often remained undetected. As the road workers in this study wore the safety garments over blue overalls (as frequently worn by road workers) there was no contrast between the blue overall and the blue safety garment. Further, as the foveal region is relatively blue-blind, and sensitivity to blue light diminishes in the periphery (Sperling, 1986), this result was expected. This result clearly demonstrates the importance of conspicuous safety garments being worn by road workers.

4.7 The Garments were More Conspicuous Against Rural than City Backgrounds

Overall, detection times were shorter against rural backgrounds compared to city backgrounds The difference was statistically significant. The shorter detection times were particularly evident in two rural conditions that were uncluttered (R2, R12). This result was expected, and is supported by both laboratory and real-life studies that have consistently shown targets are less visible against a complex background, or where there is visual clutter (e.g., Boersema & Zwaga, 1985; Boersema, Zwaga & Adams, 1989; Cole & Hughes, 1984; Cole & Jenkins, 1984). Evaluation of individual colours showed fluorescent yellow with reflective stripes, combined yellow-orange with reflective stripes, fluorescent green, white, and blue, were more conspicuous against a rural background, whereas fluorescent orange, fluorescent yellow, and fluorescent orange with reflective stripes had slightly longer detection times against rural backgrounds compared to city backgrounds.

4.8 Detection Times for the Garments were not Longer for Colour Vision Impaired Participants

Detection times by vision impaired participants, for each of the test garments, was similar to those for participants with normal colour vision . Although fluorescent orange had the longest detection time, it should be noted that this coloured garment was shown in the peripheral position 3, which also showed long detection times for participants without colour impaired vision. The difference in detection time for colour impaired participants was, however, greater for the fluorescent orange than for the fluorescent yellow.

The results obtained in this study are not consistent with results reported by Januszke and Simpson-Lyttle (1996) where red-orange was considered more conspicuous for visually impaired participants. However, both the study by Januszke and Simpson-Lyttle (1996) and this preliminary study used a small number of participants (3 and 5 respectively). Further, the specific impairment for each participant was not determined in either study. In the current study, only one participant had severe colour vision impairment and was not able to detect the red test garment.

To draw conclusions about colour conspicuity for people with colour impaired vision, a larger sample, with specific impairments known, would need to be assessed. As up to 9% of the population suffer various degrees of abnormal colour vision (Bloomer, 1990; Coren & Ward, 1989), further assessment of those with colour vision impairment is considered relevant.

4.9 Research Method and Eye Movement Analysis

Eye scanning patterns observed showed participants primarily fixated on the central tracking task, and scanned the road scenes only briefly. The participants detected the road workers with peripheral vision while focusing on the central task (driving simulation). The considerably slower detection times, evident when the road worker was in the most peripheral positions 3 and 9 (o'clock), also indicated that participants were concentrating on the central task. This is consistent with research evidence reported by Ikeda et al. (1975) where peripheral reaction times were significantly longer as the central task became more complex. Driving performance (central task error) did not correlate with detection time for any of the eight test-garments. These factors serve to demonstrate that the experimental procedure simulated a real-life driving situation in a controlled manner.

In comparison, the field study conducted by Januszke and Simpson-Lyttle (1996) did not parallel a real-life driving situation. Not only were there six road workers present at each work site, all attired in a different coloured garment, but the observers knew what to expect, and were seated in the rear seat of a vehicle. This is not consistent with a driver scanning the environment. No weather, brightness, or light conditions were reported, nor were colour measurements of the garments.

4.10 Recommendations

The results from this study showing search conspicuity trials produced shorter detection times than attention conspicuity trials clearly strengthens the case for the use of a standard coloured safety garment so drivers can associate a certain colour with road workers, which in turn will increase detection rates and safety of road workers. Although the difference in detection times may appear to be small, a vehicle travelling at 50 km/h travels 14 metres per second, which highlights the importance of road workers wearing a conspicuous safety garment.

Fluorescent orange and fluorescent yellow were the two most conspicuous colours. When results were combined, detection time for the fluorescent orange was marginally shorter, but there was no statistically significant difference between them. While it was not possible to make a clear decision between fluorescent orange and fluorescent yellow, they were clearly more visible than any other colours tested. When individual road scenes were evaluated, results indicated that the brighter fluorescent yellow (compared to fluorescent orange) was more visible against darker backgrounds, while fluorescent orange was more visible against brighter backgrounds.

It was evident that conspicuity was reduced for garments with reflective stripes. Therefore, it is recommended that reflective stripes not be used on safety garments worn in daylight conditions. If reflective stripes need to be on the garments, fluorescent orange would be the better choice as yellow with reflective stripes was less visible when results were combined.

Detection time for the fluorescent green was inconsistent, and use of this colour would not be recommended. Due to the considerably slower detection times for white and blue, neither of these colours would be recommended for use either. Neither would red be recommended, as it is known that some people with colour impaired vision are unable to detect this colour.

No comparisons were made in this study between experienced and inexperienced drivers. As it has been shown that increased central task complexity decreases peripheral task performance, it may be advantageous to determine whether there is a difference in detection times between experienced drivers and inexperienced drivers who may find the central driving task more complex.

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