

Transport Research Laboratory



Road Worker Conspicuity

Daytime & Night Time

by S Helman and M Palmer

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CLIENT PROJECT REPORT



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by **S Helman and M Palmer (TRL)**

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(Paul Mitchell)

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Note regarding colour images:

The research undertaken used items of road worker clothing meeting the requirements of BS EN471, these are illustrated within this report. Due to limitations of photographic and printing equipment and computer displays, the rendering of colours displayed cannot match that of the original clothing. Illustrations should be used for guidance only.

Implementation hierarchy

The recommendations made within this report should be implemented using the following hierarchy:

1. Education

The biggest benefit will be obtained from raising road worker and driver awareness of conspicuity issues, approached via the following areas:

Road Workers & traffic Officers need to understand:

- The distances at which it is likely they are being detected by drivers who are not specifically searching for them
- How conspicuous they really are, particularly within their working environment
- The difficulties that approaching drivers may have identifying workers who are in close proximity to works vehicles, particularly those marked with high-visibility colour schemes or displaying warning beacons

Drivers need to understand:

- The likelihood of road workers being present
- Their relative lack of conspicuity, especially at night, even when wearing high visibility PPE
- "Yellow lights = people"

2. TOS uniform

The TOS uniform conspicuity should be improved by incorporation of retro-reflective material to the ankle area and, ideally, by the use of fluorescent yellow trousers.

3. Road workers & vehicles

There is no clear advantage to using a particular PPE/vehicle colour combination. However:

- There may be some specific situations in which the combination of orange PPE and white vehicles, or yellow PPE against orange vehicles (for the HA salting vehicle fleet), are beneficial to road worker safety
- The combination of white vehicles and orange PPE may be easiest to see, but the combination of yellow PPE against white vehicles could lead to 'blending' and reduce road worker conspicuity

Executive summary

The Highways Agency wish to establish whether current best practice standards for PPE are adequate to ensure road worker conspicuity under night time and daytime conditions.

The HA commissioned TRL to carry out research focused on the following research questions:

1. What are the perceptions and opinions of road workers¹ with regard to their conspicuity?
2. At what distances are road workers seen in a naturalistic but controlled track study under daytime and lit/unlit night time conditions²?
3. Do different colours of PPE vary in their visibility under daytime and lit/unlit night time conditions?
4. Are there differences between subjective ratings of visibility for different coloured materials (representing PPE) against different background colours (representing works vehicles)?
5. What are the expectancies of drivers regarding the likelihood of encountering road workers in the proximity of vehicles stopped at the side of the road with flashing lights or beacons?

In addition, when the project was underway, the team were asked to comment, if possible, on any differences apparent in those participants with colour vision deficiencies.

The research consisted of the following activities:

1. Consultation with road workers about their perceptions of conspicuity.
2. Track studies during night time and daytime conditions, in which participants were driven past one of two mocked-up scenarios on the TRL track, and asked to comment on the things that grabbed their attention. This was designed to measure detection distance of PPE-wearing mannequins under relatively naturalistic driving conditions.
3. A study in which participants rated the subjective visibility of difference combinations of PPE material and background colours.
4. A post-drive interview in which participants were asked about their expectancies on encountering vehicles with flashing lights and beacons in their everyday driving.

Conclusions

Road workers are not highly conspicuous, even in hi-viz PPE

The first conclusion of this report is that road workers are not as conspicuous as has been observed in previous studies that used 'search' instructions, especially at night. Detection distances of as low as 25 to 45m were observed in some night time conditions.

It is highly likely that road workers in general are not aware of this and are likely to over-estimate their actual levels of conspicuity.

¹ "Road workers include all operatives working on the Agency's network who are directly exposed to risk from network users. These include all workers contracted to work for the Agency in traffic management activities and incident support services, maintenance and renewal schemes, vehicle recovery operators and any other activities where live traffic is present." Highways Agency 'Aiming for Zero', 2010.

² Note that it was not the intention to give absolute values that can be applied to real-world driving scenarios; however the 'ball park' distances obtained might be indicative.

Drivers do not necessarily expect to see road workers

The participants in this study who were interviewed about this issue showed a varied set of expectancies regarding encountering road workers in everyday driving. More than half the participants reported that they would not expect to see people where a vehicle with flashing lights is stopped at the roadside.

There was no obvious 'overall' impact of different types of PPE on detection distance

There were no firm data in the current study to suggest that any one PPE colour or design granted any advantages in conspicuity over any others, although there were some (statistically non-significant) trends in the data. For example, when additional trackside lighting was switched on yellow PPE seemed to have a slight advantage in one scenario at night, while orange seemed to have a slight advantage in another scenario at night.

The data from the colour board suggest that orange PPE against a white background at night is more visible than other combinations. However, before any wholesale to vehicle and PPE colour change is recommended, further research should be undertaken to replicate this in naturalistic settings and establish which colour different combinations are advantageous or detrimental to conspicuity.

Ankle markings and fluorescent trousers would be advantageous

Since the current HA Traffic Officer uniform does not have any ankle-markings, it would be of benefit to fit such retro-reflective materials to the ankles of this PPE design, particularly since low-beam headlamps will not effectively illuminate retro-reflective material on a jacket. The results of the daytime Traffic Officer scenario suggest that daylight conspicuity would be improved by the use of yellow fluorescent trousers by Traffic Officers.

White may be the most appropriate vehicle colour at night, and orange PPE against white vehicles may be the easiest to see

Although it is not advisable to reach a conclusion from the colour wheel study with respect to vehicle colour, the findings do at least suggest that white may be the best overall colour to consider, when day and night time visibility is taken into account. The data also suggest that orange would provide the best colour PPE for occasions when workers are stood in front of a white vehicle, but yellow PPE against white was rarely selected by participants as the easiest to see.

Colour deficient vision

Finally, the data from subjective ratings of visibility of PPE/background combinations suggested that these individuals did not behave any differently to those with normal colour vision.

Recommendations

The following main actions are recommended:

General actions

- **Educate road workers and Traffic Officers about their actual levels of conspicuity**

The key recommendation of this report is that all people who work on or around roads should be educated as to the distances at which it is likely they are being detected by drivers who are not specifically searching for them.

The information described in Section 2 of this report has established road workers' knowledge of their conspicuity and their over-optimism regarding detection distances, especially at night. An appropriate training and education package should be designed, following the following the principles outlined in Section 9.1, with the specific intention of ensuring road workers have a realistic understanding of their actual conspicuity within their working environment.

Workers should also be made aware of the difficulties approaching drivers may have identifying workers when they are in close proximity to works vehicles, particularly those marked with high-visibility colour schemes or displaying warning beacons.

- **Educate drivers with respect to the likelihood that road workers are present in the kinds of scenarios encountered in everyday driving**

Campaigns targeting drivers' knowledge and understanding of road worker safety should include reference to the likelihood of road workers being present, and their relative lack of conspicuity, especially at night, even when wearing high visibility PPE. Careful management of how messages are delivered will be needed. For novice drivers, the DSA Hazard perception and Theory tests could include specific road worker examples.

Actions specific to the Traffic Officer Service

- **Adopt ankle retro-reflective materials**

Retro-reflective materials should be fitted to the ankle areas of TOS uniforms, to aid conspicuity at night when in the vicinity of cars using dipped headlights.

- **Adopt fluorescent trousers**

TOS uniform should incorporate yellow fluorescent trousers to improve daytime conspicuity.

Recommendations specific to other road workers

- **Consideration should be given to the specific circumstances under which different colours of PPE might be beneficial**

The data do not support the notion that a change to orange PPE is required 'across the board' to increase safety. However it should be considered whether there are some specific situations in which the combination of orange PPE and white vehicles, or yellow PPE against orange vehicles for the HA salting vehicle fleet, may be beneficial to road worker safety.

- **Consider the use of white vehicles**

The data suggest that white vehicles are more visible than other colours at night. Although the combination of white vehicles and orange PPE may be easiest to see, the combination of yellow PPE against white vehicles could lead to 'blending' and reduce road worker conspicuity.

Should a mandated change to vehicle and PPE colour be anticipated for workers on the HA Network, this should be planned carefully to avoid any 'blending' issues during any changeover period.

1 Introduction

1.1 Highways Agency's concerns

High visibility clothing is used widely by road workers (and other industries), and also by many leisure users. In most cases the wearer believes there will be an improvement in their safety, as approaching drivers may detect them earlier and so be able to take any necessary avoiding action sooner.

High-visibility clothing contains two elements which may help drivers achieve this earlier view; these elements are fluorescent material (for daytime conspicuity), and retro-reflective material (for night time conspicuity). These two materials work in different ways, and it is commonly accepted that a single item of clothing must combine them to give optimum results, especially when considering combined daytime and night time effectiveness.

Combinations of fluorescent and retro-reflective material for professional use in PPE are detailed in BS EN 471:2003 (High-visibility warning clothing for professional use – Test methods and requirements), with minimum areas of fluorescent and reflective (or combined) material for each of its three classes. The specification also details the colour options available to users. This is outlined in Appendix N.

The HA requires workers on its high speed roads to wear high visibility clothing to BS EN471 Class 3. This research was commissioned to verify that this was appropriate and to provide guidance on workwear arrangements for road workers and HA Traffic Officers.

The following research questions were addressed as the centre of this work:

1. What are the perceptions and opinions of road worker with regard to their conspicuity?
2. At what distances are road workers seen in a naturalistic controlled track study under daytime and lit/unlit night time conditions³?
3. Do different colours of PPE vary in their visibility under daytime and lit/unlit night time conditions?
4. Are there differences between subjective ratings of visibility for different coloured materials (representing PPE) against different background colours (representing works vehicles)?
5. What are the expectancies of drivers regarding the likelihood of encountering road workers in the proximity of vehicles stopped at the side of the road with flashing lights or beacons?

In addition, when the project was underway, the team were asked to comment, if possible, on any differences apparent in those participants with colour vision deficiencies.

1.2 Previous pedestrian conspicuity research

There is already substantial literature on pedestrian conspicuity. Langham and Moberly (2003) provide a useful review of this literature, and highlight the fact that the issue is a complex one; the ease with which a given stimulus will be detected depends on a wide range of factors including at least the visual characteristics of the stimulus itself, the visual scene in which it is presented (including lighting and background conditions) and the goals and expectations of those viewing the scene.

A variety of methods have been used to examine pedestrian conspicuity, including laboratory studies using static pictures, video of road scenes, closed track-based studies

³ Note that it is not possible to give absolute values that can be applied to real-world driving scenarios; however the distances obtained are believed to be indicative of real-world conditions.

using mock-ups of road scenes and studies using entirely naturalistic⁴ driving on real roads. Langham and Moberly (2003) suggest that given the range of factors that impact on pedestrian conspicuity, "...methodological eclecticism may...be a useful strategy" (p358). In other words, using a variety of methods is of benefit if it is likely that a large number of variables impact on conspicuity, since different methods have different strengths and weaknesses in respect of manipulating these variables.

There are two important features of the literature for the purposes of the current study. Firstly there is an important distinction in the literature between two types of conspicuity; researchers contrast the extent to which something is visible if the viewer is actively searching for it (search conspicuity) and the extent to which something 'grabs the attention' of a viewer even if they are not actively looking for it (attention conspicuity). Secondly, almost all research into high visibility PPE has involved search conspicuity instructions; researchers have examined the effect of different colours and designs of PPE on conspicuity in a variety of driving settings and under a range of lighting conditions (e.g. Sayer et al., 1998; Sayer & Mefford, 2000, 2004, 2005, 2006; Sayer & Buonarosa, 2008), but in almost all work, drivers are specifically asked to look out for pedestrians.

Detection distances when using such an approach (i.e. search instructions, with high visibility PPE) are often very high; for example Sayer and Mefford (2005) showed that drivers' average (mean) detection distances of pedestrians wearing high-visibility vests in daytime conditions were 195m (for high complexity scenes such as towns) and 266m (for low complexity scenes such as rural roads). Sayer and Mefford (2004) showed that the mean detection distance when drivers searched for moving pedestrians while driving through mock roadworks at night (with illumination from car headlights and roadwork lighting) was over 300m for PPE including reflective strips.

These kinds of distances correspond, even at quite high speeds, to reasonable safety margins; for example at 60mph (around 27m/s) a 300m detection distance corresponds to approximately 12 seconds of decision time for a driver. However, such distances relate to the detection of pedestrians for which drivers are actively searching. Therefore they should not be taken as indicative of the detection distances that are likely under everyday driving conditions; when driving 'for real', it is extremely unlikely that drivers spend all of their time actively searching for pedestrians, given the large number of other things to which they are likely to pay attention (e.g. other vehicles, traffic signs and signals, in-car devices such as satellite navigation systems, and other in-car and out of car distractions). This is likely to be even more true of inexperienced drivers (especially those in their first year of driving) who have been demonstrated to have less well-developed hazard perception skills (McKenna & Horswill, 1999; McKenna & Crick, 1994).

It is challenging to obtain an absolute estimate of drivers' detection distances for pedestrians during everyday driving when they are not being instructed to search actively for those pedestrians. However it can be argued (e.g. Langham & Moberly, 2003) that measurements of attention conspicuity are likely to be better estimates of 'real world' detection distances than are measurements of search conspicuity, since they remove the explicit search instruction which it can be argued is lacking during everyday driving. A classic experiment by Cole and Hughes (1984) showed that drivers' detection of discs of various size and levels of reflectivity was around three times more likely under 'search' instructions than when drivers were simply asked to report everything that grabbed their attention in the driving scene. There is little if any research however looking into measuring drivers' detection distances of pedestrians under attention conspicuity instructions. This is unfortunate, especially in light of the fact that pedestrians are known to overestimate their conspicuity, particularly at night (see e.g. Tyrell, Patten and Brooks (2002).

⁴ This involves the looking at and recording behaviour in a natural setting, with no attempt made to influence the participants.

This study approaches the issue of PPE in operational settings in two key ways. Firstly, by placing PPE into realistic road environments (mocked-up road-worker scenarios on TRL's closed track system) and without instructions to search specifically for pedestrians, it is possible to determine whether observers recognise and comment on the existence of workers and whether one colour scheme of those examined produces an earlier or more frequent detection than others. Secondly, by allowing observers to grade combinations of background and PPE colours it is possible to produce guidance on optimum PPE and vehicle colour combinations to avoid or reduce the potential for 'blending', where a worker is camouflaged against a vehicle. Additional data were collected during post-drive interviews.

Another issue is that identifying a 'best' colour for PPE in specific applied settings may not enable direct assessment of possible 'camouflage' effects. If road workers are operating in close proximity to vehicles which have their own conspicuous colour schemes with retro-reflective areas and warning beacons, these features may reduce the visibility of the PPE relative to other backgrounds. Therefore as part of the study, a parallel experiment was run in which people were asked to rate the visibility of different colour/background combinations. This provided data to complement the main track trial.

1.3 Overview of report

The current report covers four main sources of data.

1. Data gathered from an initial consultation with road workers in the field; this consultation was designed to capture the opinions and views of road workers with respect to their own conspicuity, and to set a context for the remainder of the work.
2. Data from two track studies (two different mock scenarios) on drivers' detection distances for people wearing different colours of PPE, under different lighting conditions (daytime, night lit, night unlit), when drivers were not instructed specifically to search for mannequins. These studies were designed to establish the extent to which detection distances varied with PPE and/or lighting conditions, in realistic but controlled scenarios.
3. Data from a study in which participants (after they had carried out the relevant track trial) were asked to rate the visibility of different colours of PPE material (yellow and orange) on different background colours (yellow, orange, white, silver). This study was designed to establish subjective estimates of visibility for different colour/background combinations that correspond to PPE and vehicle colours.
4. Data from interviews carried out after the above studies regarding memory for the track scenarios, and general expectations regarding the likelihood of seeing people around similar scenarios in everyday driving.

In addition, data from those participants identified as being likely to have some kind of colour deficient vision were examined separately to establish whether there were any findings specific to them.

This report is structured as follows:

Chapter 2 reports the initial consultation with road workers that sets the context for the studies described in later chapters.

Chapters 3 and 4 reports the track studies, and relevant quantitative data from post-drive interviews.

Chapter 5 reports qualitative data from the post-drive interviews.

Chapter 6 reports data from the ratings for colour/background visibility.

Chapter 7 reports data from those participants identified in the sample as having colour deficient vision, from the colour/background visibility ratings.

Chapter 8 discusses the main findings.

Chapter 9 draws conclusions.

Chapter 10 gives recommendations.

2 Consultation with road workers⁵

In order to understand and identify the views and opinions of road workers, an extensive consultation exercise was undertaken to identify key issues, specifically consultation with road workers, including the Traffic Officer Service, emergency services, recovery agents, and other contractors on the network.

TRL researchers visited road maintenance personnel and Traffic Officers in outstations in each of the seven Highways Agency regions, including taking part in a ride-out from one outstation in the South West region. Visits were also made with the emergency services, including two different police forces, two different fire and rescue services, an ambulance service, the Home Office Scientific Development Branch (HOSDB), the Association of Chief Police Officers (ACPO), and the Chief Fire Officers Association (CFOA). In addition recovery agents, other contractors, and the HSE were visited.

Through the consultation exercise with the road workers and their managers, information was gathered regarding the perceptions held by those working on and beside roads regarding visibility and conspicuity; this included assumptions regarding the distances at which drivers perceived road workers, and 'camouflage' effects with their vehicle and the whole incident scene. In addition road workers and managers were asked how they appraised incidents and near misses involving road workers on the HA network. Their thoughts on ways to improve their safety by addressing visibility and conspicuity issues included education of the public, procedures and practices, the uniform, equipment, and vehicle lighting. Some road workers reported currently using additional equipment in an attempt to improve their safety, such as bike lights or 'wands' on torches, as well as standard-issue equipment lights that are usually intended for a different purpose.

2.1 Key themes

The following key themes emerged from the consultation with road workers in relation to night-time conspicuity. They highlight practices, opinions and beliefs which could potentially be hazardous for road workers.

- Lack of understanding among road workers of the **limitations of their high visibility uniforms** in terms of:
 - The situations in which they were effective or not, i.e. some thought their effectiveness depended on the angle at which the light source hit them, while most did not explicitly understand that the uniforms do not work as well in a visually-cluttered environment.
 - Some focused on **professional image and/or functionality** over safety.
 - **Over-estimation of distance** at which they can be seen; there are many influences on this.
 - Belief that they are more visible with uniforms leading to potentially **greater risk taking behaviour**.
 - Lack of appreciation of the benefit of having retro-reflective and/or fluorescent material on the **lower half of the body**, although some (paramedics in particular) had purchased their own such items.

- While it is best practice for road workers to carry out their activities based on the assumption that drivers do not see them at all—especially at night time—this

⁵ The term 'road workers' is used generically here to refer to anyone whose work at times takes place on or beside a road.

practice was not ubiquitous. There was an **over-reliance on an expectancy that drivers should take responsibility for road workers' safety**:

- Drivers are expected to understand the **role of road workers** and tasks they perform.
 - Drivers are expected to correctly **interpret information** (about the presence of road workers from high visibility clothing or seeing the road workers' vehicle).
 - Drivers are expected to take **appropriate action** such as reducing speed or paying more attention.
 - There was a **widespread belief that, as well as their primary function of providing light for them to write notes, the lapel torch or peli-lights could improve safety for those who use them.**
- **Insufficient recognition of camouflage effect** with themselves and their vehicle, light 'flooding' at incident scenes causing glare to drivers, and a general belief amongst road workers that **their own conspicuity is not important** (so long as something attracts the drivers' attention):
- Indeed it was not uncommon for road workers to believe that by being near their vehicle the light helped to **illuminate** them, rather than masking them.
- It was a strong recurrent theme for road workers to feel that their safety was **heavily reliant on the visibility of their vehicle**:
- This led to road workers desiring what they perceived as an 'upgrade' in lighting on the vehicle, i.e. if currently had amber then add red lights, if currently had red lights then add blue lights.
- **Unrecognised benefit of recording near misses** and the majority of incidents **attributed to driver error** such that it was considered that driver education should be the primary method of improving their safety:
- Providing a definition of the term and guidance on how to report them would be useful to provide comparable data.

In summary, the consultation exercise revealed a range of assumptions held by road workers regarding conspicuity. Many of these assumptions may lead to workers putting themselves at risk when working on or near the road. This finding is not unexpected given previous work in the area of pedestrian conspicuity (see Section 1.2), and sets the context for the remainder of the work reported in this document. Data that explore the extent to which different PPE colours and designs elicit different behavioural responses from drivers and that shed light on the expectancy models held by drivers with respect to road workers should be useful in terms of illustrating to road workers the dangers posed by conspicuity issues.

3 Track study – HA Traffic Officers scenario

3.1 Purpose

The purpose of the first track study was to examine the influence of different colours of personal protective equipment (PPE), in different lighting conditions (daytime, night time lit, night time unlit) on the distances at which drivers mention that they have seen people (or mannequins) present at the road side. The scenario (an HA Traffic Officer Vehicle and a broken-down car positioned as if on the hard shoulder of a motorway) was designed to mimic one that would be seen during everyday motorway driving.

3.2 Method

Participants

397 members of the public were recruited through adverts placed in local newspapers, and through TRL's existing participant recruitment panel. Participants were told that the trial was concerned with 'perception of road hazards', and were paid to take part. Of the 397 participants recruited to take part in the HA Traffic Officers scenario, 209 took part in the night-time data collection (see Section 3.3) and 188 took part in the daytime data collection (see Section 3.4).

Procedure

The scenario was positioned on the TRL test track. Appendix A shows a plan view map of the track. The location of the critical scenario is also shown (bottom left of the track map; scenario relating to track study 2 is illustrated).

Participants were told that the study was focused on understanding the kinds of things that drivers notice when driving, and that they would be required (while being driven around the TRL track) to give very simple 'commentaries' on the things that attracted their attention. Participants watched a short 'training video' which explained the procedure in more detail, and they were then taken to a holding area. In turn, each participant was then driven around the track in one of the two experimental vehicles. Each vehicle had a driver who drove around the track at 40mph (by using the cruise control on the vehicle) and an experimenter who delivered instructions to the participants. Participants were instructed that as they were driven around the track, they were to say out loud the things grabbing their attention, as instructed in the video. On the first main straight section of the track, three items were placed: these were a parked vehicle (with its hazard warning lights on during Night Time trials), a yellow retro-reflective flat panel bollard, and a bend warning sign. These items were designed to encourage participants to begin commentating as soon as they began the drive, so that by the time they reached the trial scenario (see Section Appendix A) they had at least some practice in the technique.

The view from the front of the vehicle was filmed using a DVD recorder throughout the track drive, and this recording was later used to ascertain the point at which participant mentioned seeing the mannequins at the trial scenario (if at all). After one circuit of the track (shortly after passing the critical scenario) participants were asked to stop their commentary and were then taken to the next stage of the overall testing schedule (the 'colour board', see Section 6). Finally, participants were returned to the main TRL building to take part in an eye test and a short interview before being paid and allowed to leave. Participants were told at the beginning of the evening that if they wished to cease their participation in the study at any time, without giving a reason, they could simply tell one of the experimenters.

Appendix B, Appendix C and Appendix D show the instructional materials used at the various stages of the trial.

Design

The key measure of attention conspicuity of the mannequins used in the scenarios (see Section Appendix G) was the point at which they were mentioned in participant commentaries (measured as the number of video frames before the experimental car reached the scenario, see 3.3). Coders noted the frame counts at which the commentary first included any word that clearly and unambiguously referred to at least one of the mannequins (typical terms included: 'road-worker', 'dummy', 'policeman' or 'person'), and then calculated the difference in frames between this point and a pre-determined reference point at the scenario.

Two other measures of interest related to the questions asked in the post-drive interview. The first related to whether participants remembered seeing people at the critical scenario, and if so, where they were stood and which was seen first. The second related to participants' expectations in their everyday driving of seeing people near vehicles with amber flashing lights.

Each participant saw the scenario only once on the drive, and therefore experienced only one of the experimental conditions. The experimental conditions varied in terms of the PPE worn by the mannequins, and the lighting conditions. Lighting conditions were either daytime, night time (street lights on) or night time (street lights off); note that the daytime data were collected nine months after the night time data and therefore these two sets were analysed separately. Three types of PPE were used across all lighting conditions; these were yellow PPE, orange PPE, and multi-coloured HA officer PPE. In addition, two other variants of the multi-coloured HA officer PPE were used only in the daytime condition, and are therefore presented in a separate analysis with the daytime data only.

The design described enabled an assessment of whether the different types of PPE led to different detection distances under the various lighting conditions.

More detail (and pictures) of the PPE types can be found in Appendix E.

Scenario details

The trial scenario consisted of a Highways Agency Traffic Officer vehicle parked (fend off, i.e. angled with the front of the vehicle towards the main carriageway) behind another car, as if stopped on the hard shoulder of a motorway. Two mannequins were used to mimic Traffic Officers; one placed to the rear nearside (left) of the Traffic Officer vehicle, and the other to the rear offside (right) of the 'broken down' vehicle.

See Appendix G for details of the scenarios used in both track studies.

3.3 Results – night time data

Track data – night time

The frame count was calculated for each participant in the study. This is a count of the number of frames before the reference point in the scenario that the first mention of a dummy (or person etc.) was made. It cannot be more than 400m from the scenario due to the line of sight limitations on the track, which at 17.88m/s (40mph) and 25frames/sec is a maximum of 500 frames. Hence no frame count value greater than 447 can relate to the driver actually seeing the mannequin.

In practice restricting frames counts to between -125 and 250 generated a Normal distribution (confirmed by the Kolmogorov-Smirnov test $p=0.055$ – based on all the

frame data), and very few outliers. This corresponds to times of 10 seconds before to 5 seconds after the scenario position at approximate distances of 180m before to 90m after⁶. Restricting the data in this way resulted in approximately normally distributed data for each of the two scenarios, meaning that it was appropriate to use parametric statistical procedures for testing of differences between the conditions.

The mean frame counts were calculated, and are shown along with standard deviations in Table 3-1 below. The data are also shown in Figure 3-1.

Table 3-1: Mean frame counts and standard deviations for each PPE/lighting condition, scenario 1, night time data⁷.

PPE Colour	Lights	Valid N	Mean	SD
Yellow	Off	22	39.77	61.52
	On	27	47.37	86.16
	Total	49	43.96	75.44
Orange	Off	28	40.46	60.76
	On	30	62.93	64.02
	Total	58	52.09	62.95
HA multi	Off	21	43.24	67.72
	On	25	35.28	50.25
	Total	46	38.91	58.32

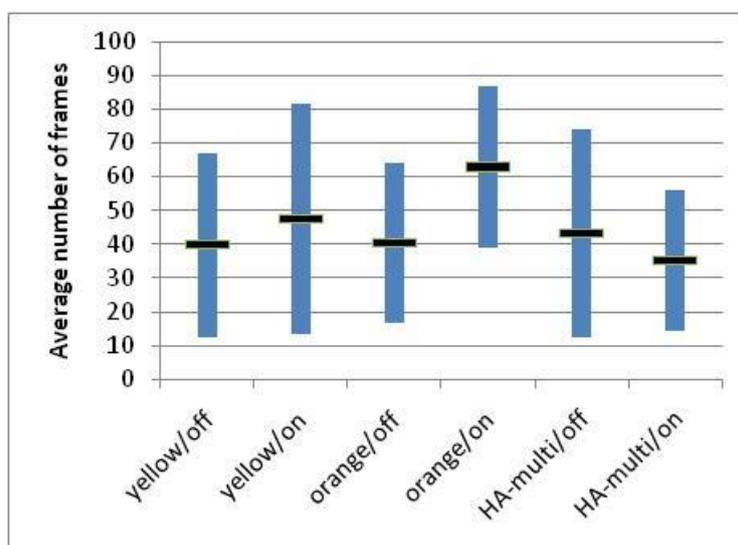


Figure 3-1: Mean frame counts (with 95% confidence intervals) for each PPE/lighting condition, scenario 1, night time data.

⁶ Participants who gave responses after the scenario were included as their data are relevant to the estimation of the average 'detection distance'.

⁷ Note that due to missing data because of equipment failures (37 participants, spread roughly evenly across the conditions), and due to a number of participants not mentioning the mannequins at all (16 participants, spread roughly evenly across the conditions), and three outlying data points removed before data were analysed, the N in this table is smaller than the total number of people tested.

The data show very little obvious difference in the frame counts of the different PPE/lighting conditions. An ANOVA (analysis of variance) did not find any statistically significant differences between the colour, the light condition or the interaction between colour and light condition. Post-hoc tests also did not find any statistically significant findings. From this we can conclude that in terms of attention conspicuity, as measured by the commentary method used, there were no obvious differences between the different PPE colours used in night time conditions, either under streetlights or not. There is a very slight trend in the data towards orange PPE leading to higher detection distances than other conditions when the lights are on, although the large variability in the measure makes it impossible to draw any firm conclusions.

Perhaps the key finding from the scenario is that the absolute detection distances across the various conditions vary between 35 and 62 frames; this is equivalent to roughly 1.4 and 2.5 seconds, or at 40mph between 25 and 45m. These distances are much smaller than the assumed detection distances identified in previous research regarding high visibility clothing (see Section 1.2). An additional analysis was run based on the participants' answers to question 11 in the post-drive interview, which asked if they had been actively looking for the mannequins/people at the scenario, or if they had 'just happened to notice' them. This analysis revealed that those participants who stated that they were 'actively looking' for people at the scenario mentioned the mannequins earlier in their drives than did those participants who stated they 'just happened to notice', and that this did not differ with lighting condition or PPE colour. For those participants who 'just happened to notice', detection distances varied between 17 and 42 frames; at 40mph distances of between just 12 and 29m.

Interview data – night time

The frame count variable was designed to give an indication of the attention conspicuity of the mannequins. However, in order to gain a better understanding of the relative conspicuity of the different mannequins in each scenario, and in each condition, it was necessary to rely on retrospective reports from participants in the post-drive interview. All participants were asked two key questions:

1. How many mannequins do you recall seeing at the scenario?
2. What was their location within the scenario?

To assist with the second question, a plan view of the scenario was presented to participants (see Appendix M). A grid overlay was used to code responses; this is shown in Figure 3-2 with the correct locations of mannequins marked.

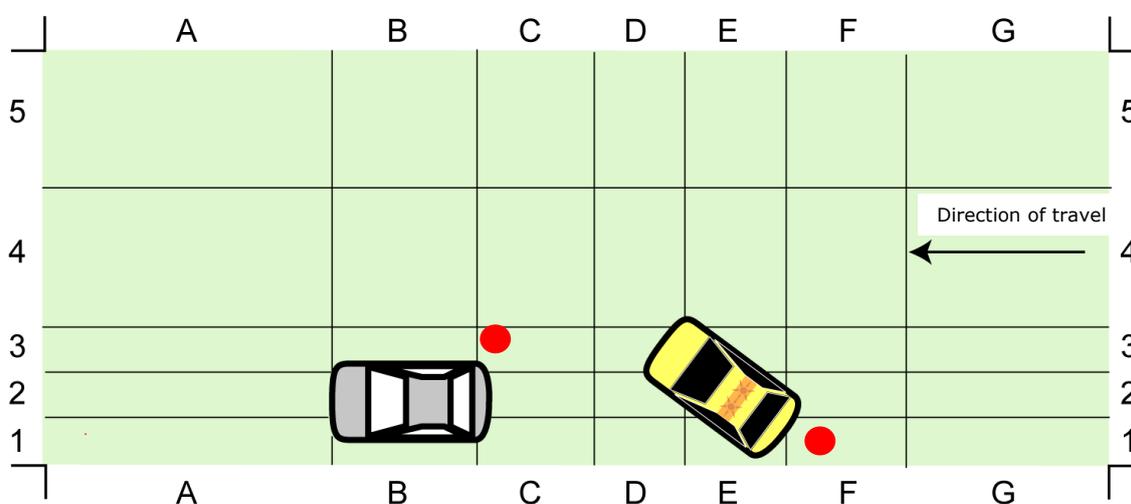


Figure 3-2: Plan view of Scenario 1 with correct locations of mannequins marked (red circles).

3.3..1 How many mannequins did people recall seeing?

Table 3-2 shows how many people recall seeing different numbers of mannequins. The majority (around two thirds overall) of people recalled seeing the correct number of mannequins (two), while around a third of people recalled seeing only one, or none. A small number of people reported seeing more than two mannequins. The number of mannequins recalled does not seem to differ with PPE or lighting conditions.

Table 3-2: Counts of how many people recall seeing how many mannequins in each condition – Scenario 1 night time data

Lights	PPE colour	Count (proportions in parentheses) of mannequins seen			
		0	1	2 (correct)	3+
Off	Yellow	2 (6%)	8 (22%)	21 (58%)	5 (14%)
	Orange	0 (0%)	12 (32%)	25 (68%)	0 (0%)
	HA multi	1 (3%)	7 (24%)	19 (66%)	2 (7%)
On	Yellow	1 (3%)	9 (26%)	22 (63%)	3 (9%)
	Orange	1 (3%)	4 (11%)	28 (74%)	5 (13%)
	HA multi	1 (3%)	7 (21%)	23 (70%)	2 (6%)

3.3..2 How accurate were people in remembering locations?

Participants were asked to mark on the plan picture of the scenario where they saw any mannequins. Although we would not expect recall to be perfect, the measure should give some idea of the relative conspicuity of the different mannequins within the scenario. Figure 3-3 shows the data.

Night time data

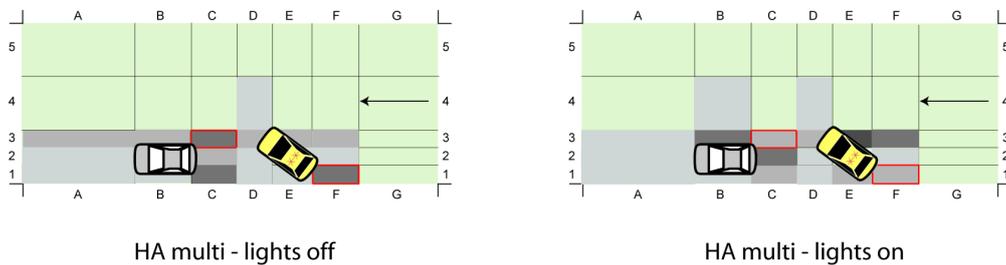
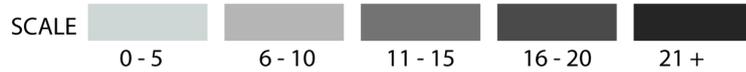
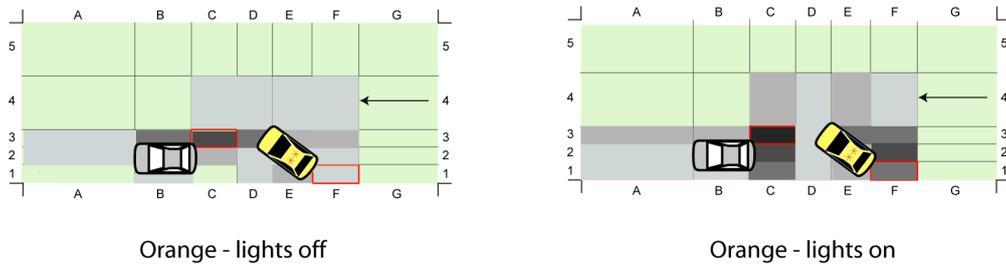
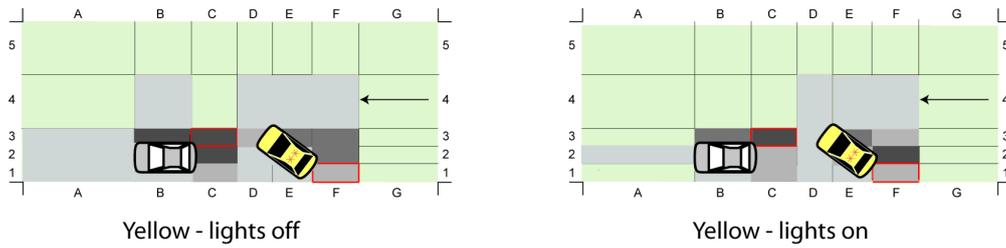


Figure 3-3: Locations of mannequins from participants' recall of Scenario 1 – night time data. The darker the grid locations, the more participants recalled seeing mannequins in that location. The red bordered grids represent the correct locations of the mannequins.

The red bordered squares in Figure 3-3 (which correspond to the red dots in Figure 3-2) are the correct locations of the mannequins. The data support the frame count data in that the only real increase in recall accuracy when the lights are on is in the orange PPE condition (i.e. the 'correct' locations are darker in the lights on condition for orange PPE, representing that more participants choose those locations). It is also worth noting that the mannequin stood behind the TOS vehicle is recalled less often than the one stood next to the broken down vehicle, possibly indicating a masking effect from the Traffic Officer vehicle's warning beacons and rear retro-reflective markings.

3.4 Results – daytime

Track data - daytime

As with the night time data, the distribution of the frame counts for mentioning the dummies was considered suitable for parametric analysis. The mean frame counts were calculated, and are shown along with standard deviations in Table 3-3. The data are also shown in Figure 3-4.

Table 3-3: Mean frame counts and standard deviations for each PPE condition, scenario 1, daytime data⁸.

All frame counts	frames to when workers were mentioned		
	Mean	Std. Deviation	N
Jacket colour			
Yellow	216.3	116.6	34
Orange	193.9	114.3	31
HA+black	158.6	118.8	40
HA+yellow	214.3	111.0	35
HA+orange	197.4	128.7	34
Total	194.9	118.7	174

⁸ Data from 14 participants who did not mention the mannequins at all (none in the yellow condition, and spread roughly equally between the other conditions) mean that the N in this table is smaller than the total number of people whose data were coded.

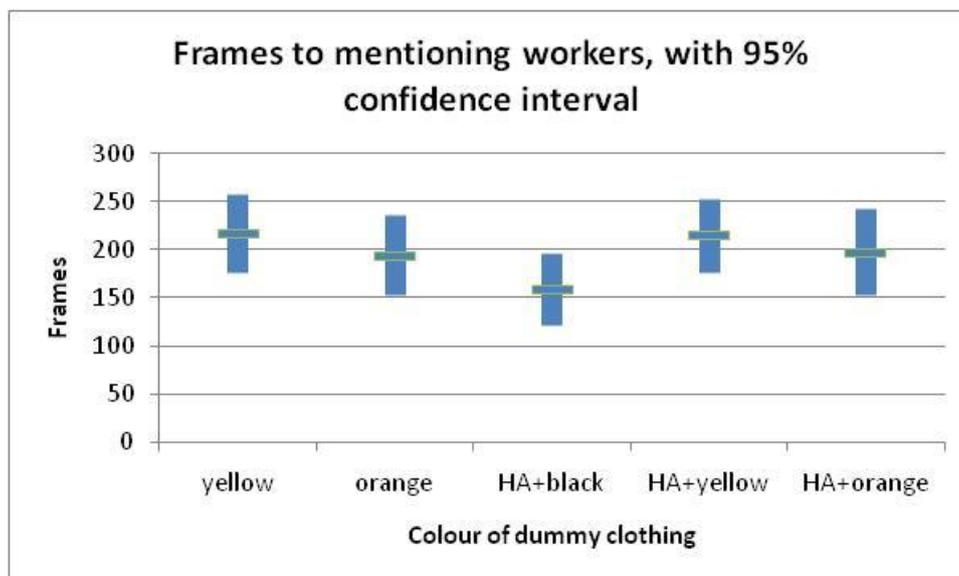


Figure 3-4: Mean frame counts (with 95% confidence intervals) for each PPE condition, scenario 1, daytime data.

An ANOVA with jacket colour as a factor was conducted, but did not find any statistically significant differences in frame count attributable to this factor. From this we can conclude that in terms of attention conspicuity, as measured by the commentary method used, there were no obvious differences between the different PPE colours used in the daytime condition. There is a very slight trend in the data that the 'yellow' and 'HA + yellow' PPE conditions led to longer detection distances than the 'HA + black' condition, although the large variability in the data make it impossible to draw any firm conclusions.

The detection distances were much larger in magnitude than those observed under night time conditions; presumably this reflects that fact that during night time visibility was limited by the trial vehicle's dipped beam headlamps and from the overhead lighting systems when they were in use. The absolute frame counts range from 159 to 216 frames, which at 40mph equate to between 110 and 150m. It is worth pointing out that these distances are still lower than those shown by previous research under daytime conditions using search conspicuity instructions (e.g. Sayer & Mefford, 2005). Analyses with respect to question 11 in the post-drive interview found no obvious pattern of differences regarding whether or not participants were actively looking for people at the scenario, or whether they 'just happened to notice'.

Interview data – daytime

3.4..1 How many mannequins did people recall seeing?

Table 3-4 shows participants' recall data for Scenario 1 in the daytime. In all PPE conditions, the majority of participants reported seeing the correct number of mannequins, with only 1 person in the entire sample reporting fewer than 2 mannequins present. The number of mannequins reported does not seem to vary with PPE colour.

Table 3-4: Counts of how many people recall seeing how many mannequins in each condition – Scenario 1 daytime data

PPE colour	Count (proportions in parentheses) of mannequins seen		
	1	2 (correct)	3+
Yellow	0 (0%)	29 (88%)	4 (12%)
Orange	1 (3%)	30 (94%)	1 (3%)
HA+black	0 (0%)	40 (93%)	3 (7%)
HA+yellow	0 (0%)	33 (87%)	5 (13%)
HA+orange	0 (0%)	32 (86%)	5 (14%)

3.4..2 *How accurate were people in remembering locations?*

Participants were asked to mark on the plan picture of the scenario where they saw any mannequins. Figure 3-5 shows the data. The data concur with the frame count data, in that there is very little difference between the conditions.

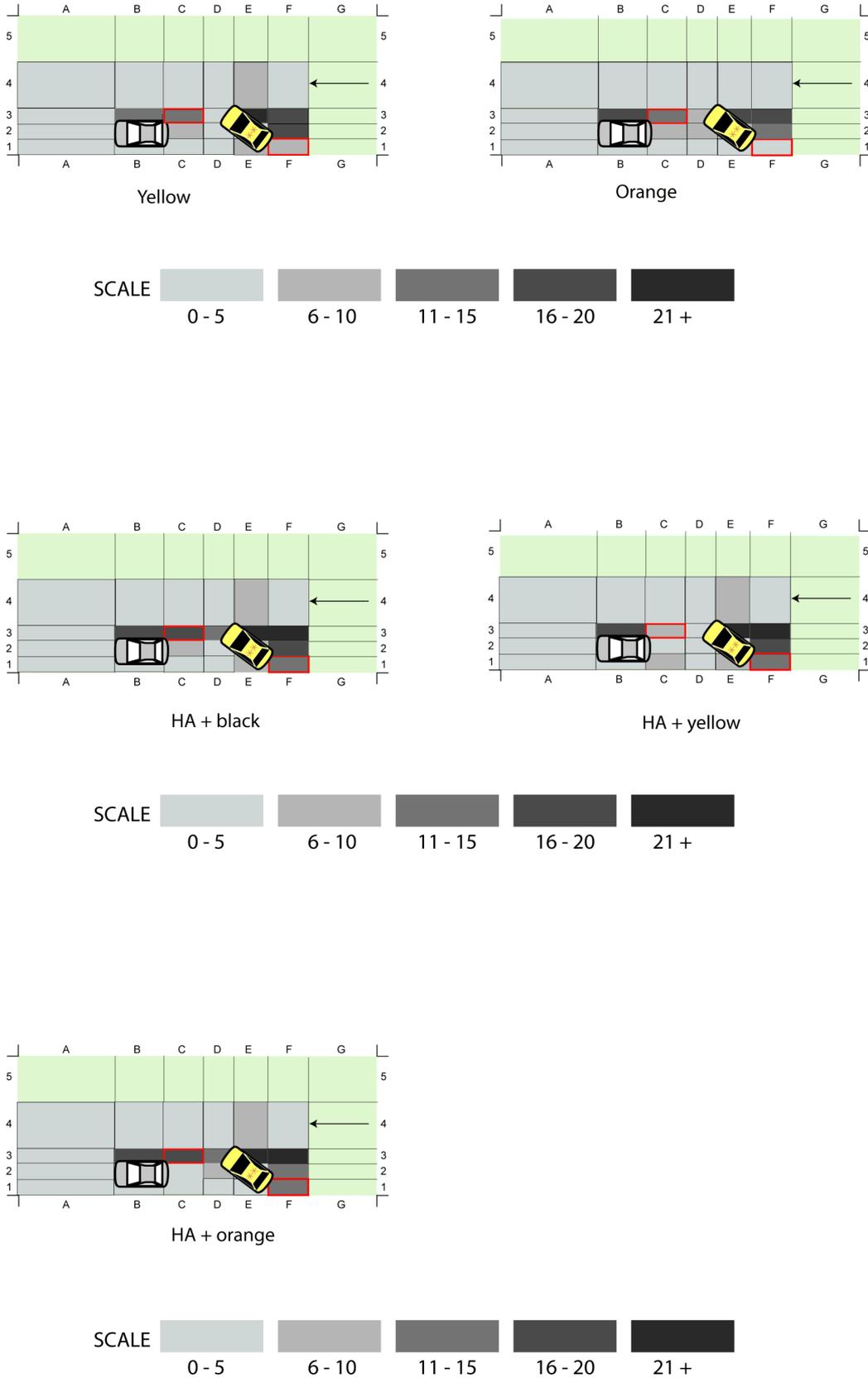


Figure 3-5: Locations of mannequins from participants' recall of Scenario 1 – daytime time data. The darker the grid locations, the more participants recalled seeing mannequins in that location. The red bordered grids represent the correct locations of the mannequins.

4 Track study – road workers TTM scenario

4.1 Purpose

As with the HA Traffic Officer scenario, the purpose was to establish if PPE and/or lighting had any impact on the distances at which drivers reported seeing mannequins at the road side, in a mocked-up scenario designed to mimic a real-world setting.

4.2 Method

Participants

207 members of the public were recruited through adverts placed in local newspapers, and through TRL's existing participant recruitment panel. Participants were told that the trial was concerned with 'perception of road hazards', and were paid to take part. Of the 207 participants recruited to take part in the HA Traffic Officers scenario, 146 took part in the night-time data collection (see Section 4.3) and 61 took part in the daytime data collection (see Section 4.4).

Procedure

The procedure was the same as that used in track study 1 (HA Traffic Officer scenario) with the exception that the critical scenario itself was different (see Section Appendix G).

Design

The measures used were the same as in track study 1, and as before each participant only experienced a single experimental condition, with experimental condition being defined by both lighting and PPE. As in track study 1, lighting conditions were either daytime, night time (street lights on) or night time (street lights off). PPE was either yellow or orange (see Appendix E for details).

Scenario details

The trial scenario for track Study 2 was a Temporary Traffic Management (TTM) Impact Protection Vehicle (IPV), parked parallel to the roadside as if on the hard shoulder of a motorway.

Three mannequins were positioned within the scenario. One was adjacent to the rear nearside of the vehicle's crash cushion, a second mid-way along the load bay, on the offside of the vehicle (as if removing a sign from the vehicle), and the third was placed against the right hand side barrier, as if placing a sign frame on the central reservation.

See Appendix G for details of the scenarios used in both track studies.

4.3 Results – night time

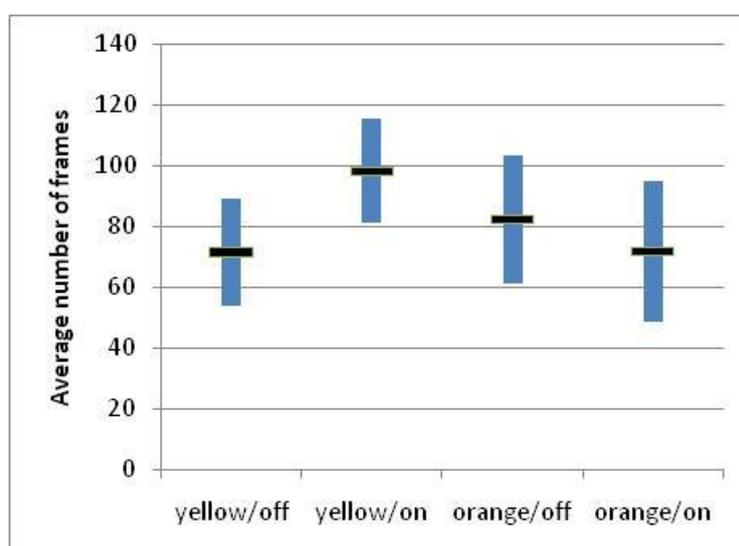
Track data – night time

The frame count was calculated for each participant in the study. This is a count of the number of frames before the reference point in the scenario that the first mention of a mannequin was made.

The mean frame counts were calculated, and are shown along with standard deviations in Table 4-1 below. The data are also shown in Figure 4-1.

Table 4-1: Mean frame counts and standard deviations for each PPE/lighting condition, scenario 2, night time data⁹.

PPE colour	Lighting	Valid N	Mean	SD
Yellow	Off	33	71.36	49.47
	On	33	98.05	48.50
	Total	66	84.70	50.43
Orange	Off	31	82.23	57.03
	On	29	71.55	60.96
	Total	60	77.07	58.71

**Figure 4-1: Mean frame counts (with 95% confidence intervals) for each PPE/lighting condition, scenario 2, night time data.**

An ANOVA did not find any statistically significant differences between the colour, the light condition or the interaction between colour and light condition. Post-hoc tests also did not find any statistically significant findings. However, there is a trend in the data suggesting that 'yellow lights on' produces earlier detection than 'yellow lights off'. This suggests that yellow is seen earlier when there is lighting than when there is not, although the lack of an effect in the main analysis suggests that this trend should be treated with caution.

The absolute detection distances across the various conditions varied between 71 and 98 frames; these distances are up to twice those seen in scenario 1 during the night time condition, and are equivalent to a range of roughly 2.8 and 3.9 seconds, or at 40mph between 50 and 70m. These distances are again much smaller than the assumed detection distances identified in previous research regarding high visibility clothing (see Section 1.2), although not by as much as the detection distances seen in Scenario 1. Analysis based on the answer to question 11 in the interview ('actively looking' or 'just happened to notice') revealed that this variable had no significant effect on detection distance.

⁹ Again there were a small number of participants who did not mention mannequins at all (seven participants, six of which were in the 'lights on' condition), and some missing data lost due to equipment failures (five participants, all in the 'lights off' condition), as well as eight outlying data points that were removed before the analysis; thus the total N in this table is smaller than the total number of participants tested.

Interview data – night time

As with Scenario 1 all participants who had experienced Scenario 2 on the track were asked two key questions:

1. How many mannequins do you recall seeing at the scenario?
2. What was their location within the scenario?

To assist with the second question, a plan view of the scenario was presented to participants (see Appendix M). A grid overlay was used to code responses; this is shown in Figure 4-2 with the correct locations of mannequins marked.

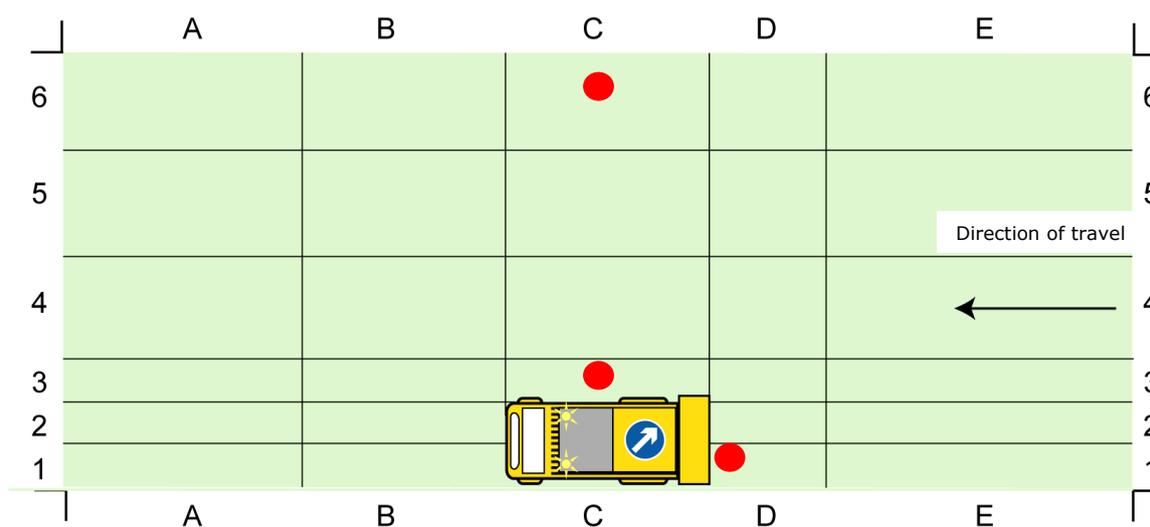


Figure 4-2: Plan view of Scenario 2 with correct locations of mannequins marked (red circles).

4.3..1 How many mannequins did people recall seeing?

Table 4-2 shows participants' recall data for Scenario 2 in the night time. When the lights are off, over two thirds of participants report seeing fewer than the correct number of mannequins (three). 31% and 23% of participants report seeing three mannequins for yellow and orange PPE respectively. This goes up to 68% and 39% respectively when the lights are on.

Table 4-2: Counts of how many people recall seeing how many mannequins in each condition – Scenario 2 night time data

Lights	PPE colour	Count (proportions in parentheses) of mannequins seen				
		0	1	2	3	4+
					(correct)	
Off	Yellow	0 (0%)	0 (0%)	17 (65%)	8 (31%)	1 (4%)
	Orange	0 (0%)	2 (7%)	21 (70%)	7 (23%)	0 (0%)
On	Yellow	1 (3%)	2 (5%)	9 (23%)	27 (68%)	1 (3%)
	Orange	2 (6%)	4 (13%)	12 (39%)	12 (39%)	1 (3%)

4.3..2 How accurate were people in remembering locations?

Participants were asked to mark on the plan picture of the scenario where they saw any mannequins. Figure 4-3 shows the data.

Night time data

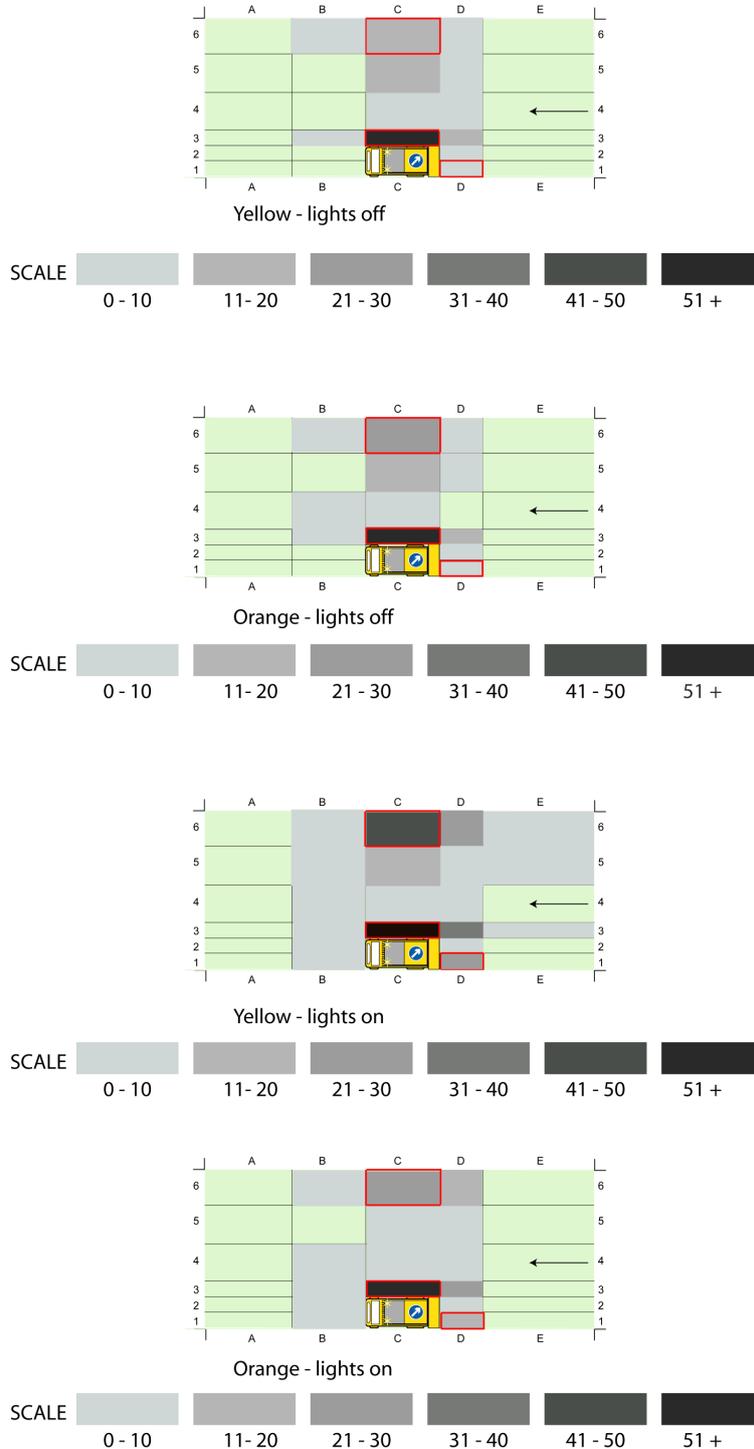


Figure 4-3: Locations of mannequins from participants' recall of Scenario 2 – night time data. The darker the grid locations, the more participants recalled seeing mannequins in that location. The red bordered grids represent the correct locations of the mannequins.

The red bordered squares in Figure 4-3 (which correspond to the red dots in Figure 4-2) are the correct locations of the mannequins. The data support the frame count data in that the only real changes when the lights are on seem to be for the yellow PPE (mimicking the slight trend in the data). Improvements in the number of participants recalling seeing the mannequin stood across the road from the vehicle seem to account for most of this effect. It is also worth noting that the mannequin stood behind the vehicle is recalled less often than the other two, in all lighting and PPE conditions.

4.4 Results – daytime

Track data – daytime

As with the night time data, the distribution of the frame counts for mentioning the dummies was considered suitable for parametric analysis.

The mean frame counts were calculated, and are shown along with standard deviations in Table 4-3. The data are also shown in Figure 4-4.

Table 4-3: Mean frame counts and standard deviations for each PPE condition, scenario 2, daytime data¹⁰.

All frame counts	frames to when workers were mentioned		
	Mean	Std. Deviation	N
Jacket colour			
yellow	203.2	104.5	32
orange	153.9	82.7	24
Total	182.1	98.0	56

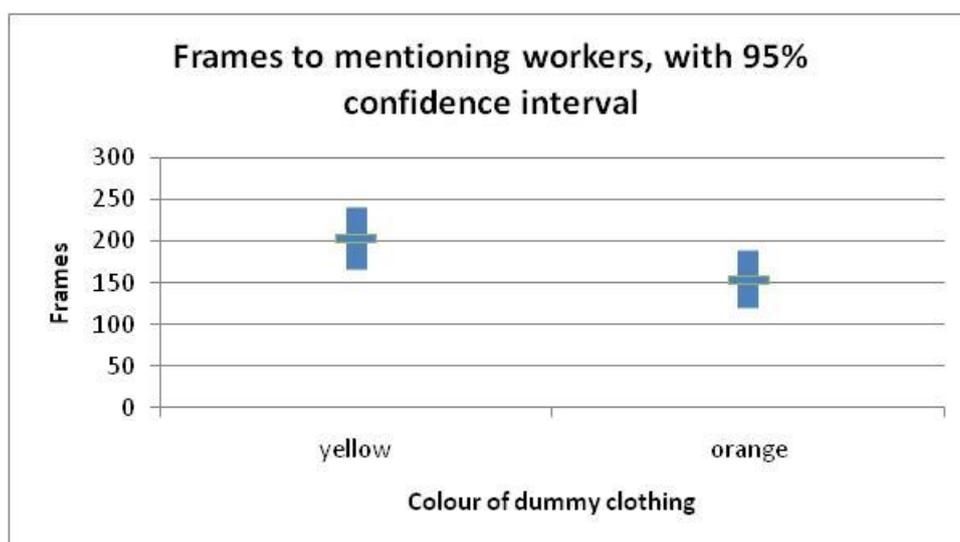


Figure 4-4: Mean frame counts (with 95% confidence intervals) for each PPE condition, scenario 2, daytime data.

An ANOVA with PPE colour as a factor was conducted, but did not find any statistically significant differences in frame count attributable to this factor. There is a very slight trend in the data that the yellow PPE condition led to earlier detection than the orange

¹⁰ Four participants did not mention dummies at all (all in the yellow condition). Missing data due to equipment failure and some outliers mean that the N in this table is less than the total number of people tested.

PPE condition, although the large variability in the data make it impossible to draw any firm conclusions.

The absolute detection distances are again higher in the daytime than in the night time conditions, and at 40mph represent a range of between 106 and 141m. Again these distances are much lower than those seen in previous research using search conspicuity instructions. Analyses with respect to question 11 in the post-drive interview found no obvious pattern of differences regarding whether or not participants were actively looking for people at the scenario, or whether they 'just happened to notice'.

Interview data – daytime

4.4..1 How many mannequins did people recall seeing?

Table 4-4 shows the number of participants who recalled different numbers of mannequins at Scenario 2 during the daytime. All but two participants correctly recalled that there were three mannequins at the scenario.

Table 4-4: Counts of how many people recall seeing how many mannequins in each condition – Scenario 2 daytime data.

PPE colour	Count (proportions in parentheses) of mannequins seen		
	1	2 (correct)	3+
Yellow	0 (0%)	32 (100%)	0 (0%)
Orange	0 (0%)	24 (92%)	2 (8%)

4.4..2 How accurate were people in remembering locations?

Participants were asked to mark on the plan picture of the scenario where they saw any mannequins. Figure 4-5 shows the data. The red bordered squares in Figure 4-5 (which correspond to the red dots in Figure 4-2) are the correct locations of the mannequins. The data support the frame count data in that the recall for mannequins seems to be slightly better under the yellow PPE condition (mimicking the slight trend in the frame count data).

Day time data

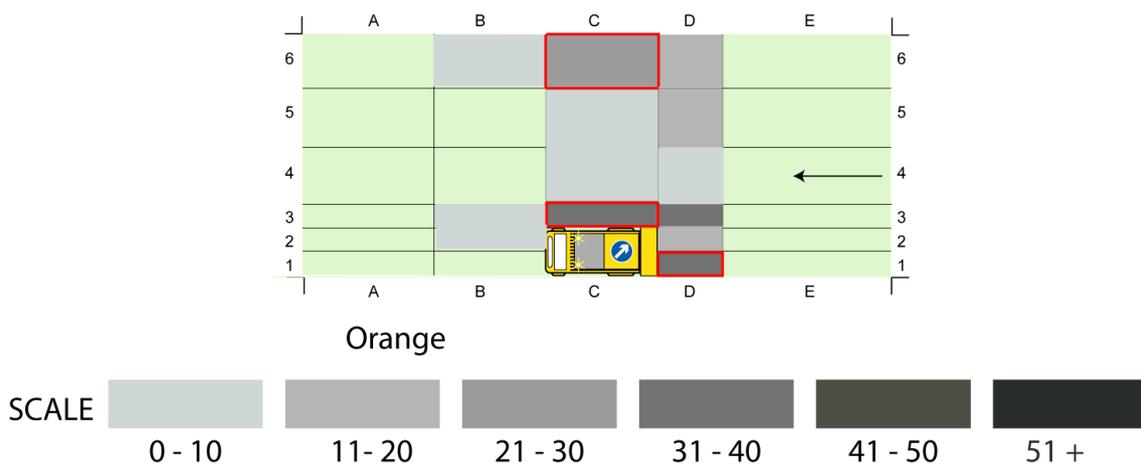
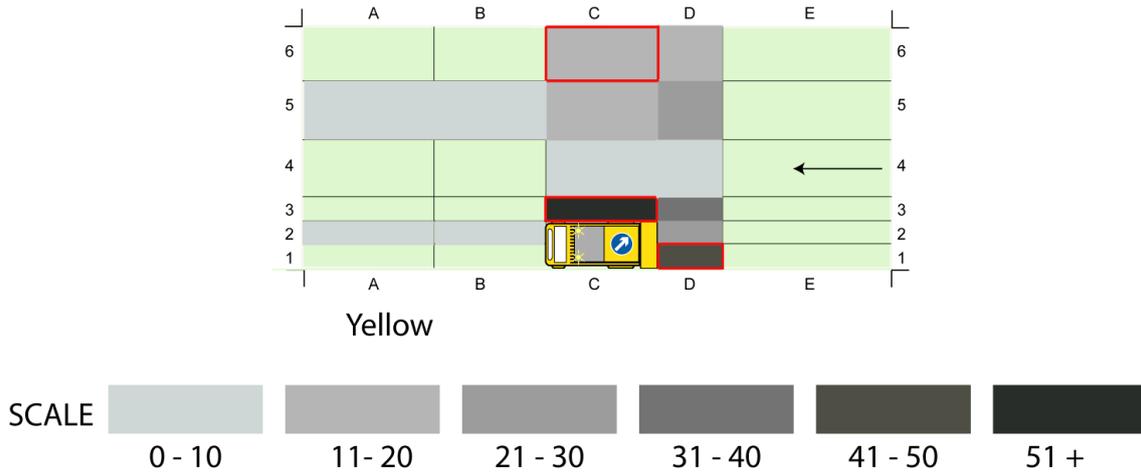


Figure 4-5: Locations of mannequins from participants' recall of Scenario 2 – daytime data. The darker the grid locations, the more participants recalled seeing mannequins in that location. The red bordered grids represent the correct locations of the mannequins.

5 Interview data – qualitative data

Another objective of the interview held after the track trials was to establish an idea of what the average driver's 'expectancy model' is regarding people at the roadside around work vehicles, based on their everyday driving behaviour. This section presents the findings from interview (see Appendix M for full interview script) data about:

- Perceptions of vehicles stopped at the roadside with flashing amber lights (interview question 15).
- Perceptions of road workers (interview question 16).
- Self reported behaviours when presented with flashing amber lights and road workers in everyday driving (interview questions 18 & 19).

Note that only data from a subset of those participants who carried out the track drives at night were analysed for this report. The data from these questions were qualitative rather than quantitative, and therefore were analysed using thematic content analysis. A random sample of thirty six interviews with participants were transcribed for the purpose of this analysis. Researchers read each transcript and coded sentences or paragraphs of the text under either broad general headings (themes) that arose. The codings were then explored in more detail; the transcripts were revisited on a number of occasions, comparing and contrasting comments between different participants. This is called constant comparison and is a method of ensuring reliability in qualitative analysis. The data were also examined by a second coder to ensure consistency in approach.

The sections below report the main themes regarding participants' perceptions of vehicles stopped at the roadside with flashing amber lights, of road workers, and self reported behaviours around these. Note that by the end of the analysis on the 36 transcripts, no new themes were emerging from the sample, and therefore it was considered that saturation had been reached. Typically saturation is defined as occurring when no new themes are emerging from discussions, and it is acceptable to stop further analysis (e.g. Glaser & Strauss, 1967).

5.1.1 *Perceptions of vehicles stopped at the roadside with flashing amber lights*

Most participants (27) expected to see a broken down vehicle when they saw vehicles at the side of the road with their flashing amber lights on.

"Generally that they've broken down, would be my first."

A number of participants (7) felt that they would see road works. Other responses included general hazards and emergency situations.

"A hazard of some sort. A stationary vehicle. Hazard light. So for example, if it was stopped on the left hand side of the road, I'd normally indicate out to the other lane in order to avoid it."

"Usually somebody's just had to stop in an emergency; a breakdown or they felt they'd needed to pull over."

Just under half of the people interviewed reported that when coming across a situation where a vehicle is stopped at the roadside with flashing lights, they would expect to see people (17); others reported that they might also expect 'some kind of hazard' (7) or debris (6).

"People. Always be aware that there might be people, especially from the motorway, they're generally on the hard shoulder. Maybe a recovery vehicle. Maybe somebody changing a tyre. Be aware for anything really."

Participants were asked where they would normally expect to see road workers when they see a vehicle stopped at the side of the road with flashing amber lights in their everyday driving. Some participants (12) answered that they would expect the road workers to be close to the vehicle (F). An equal amount of participants (7) expect them to be either on the carriageway in front of the vehicle (D) or on the hard shoulder (E). A minority of the participants expect to see people behind cones or barriers (A, 4), near the carriageway (C, 3) or in the car (B, 1).

" Around the area where the lights are, but if you saw something like that with the flashing, you would tend to look around the whole bit of the road, but you would expect to see them around the lit area if they were going to be there."

5.1..2 *Self reported behaviours when presented with flashing amber lights and road workers in everyday driving*

Most participants (34) say that they slow down when they see flashing amber lights.

"Probably slow down. So I can see what's happening more rather than speeding past it."

A minority (8) of the participants indicate that they become more alert when they see the amber light, but don't slow down or adjust their behaviour until they know what's going on.

"Yes, I would – I would be visually looking around the road to see why... what was, why that was there with the flashing amber lights and see if there's anything else I needed to see. And if it was actually in my bit of the road, I would be slowing down and I'd indicate to go around it. So, that's probably how – I'd be a bit more cautious, I would be looking for what was the problem with the lights."

The respondents give almost the same response when they are asked if and how they adapt their behaviour when they see road workers in their everyday driving. Most of the respondents slow down, and a minority adapt their behaviours when it is clear what's going on.

"Only if the area that they're in is approaching my lane of the road and you have to, you know, like if it's affecting the lane that I'm in, then yes I would slow down and look to see what space I had to go around. So, if it was in my bit of the road and I had to go onto the other lane, you know sometimes you have to go to a stop until you can get around that, and I'd be indicating to go around."

Overall the data from the interviews suggest that people's expectancy models based on their everyday driving behaviour are variable. There is by no means a unanimous expectation of seeing 'people' when observing a vehicle with flashing amber lights stopped at the roadside, and the location where people might be expected is also variable.

6 Colour board

6.1 Purpose

The track trials described in Sections 3 and 4 benefitted from good ecological validity¹¹ and generated data on the extent to which the mannequins emerged in participants' commentaries about what they saw on the track. This provided an estimate of the attention conspicuity associated with the different PPE combinations tested under relatively naturalistic driving conditions.

Another focus of this study was to try and establish which factors might be associated with changes in attention conspicuity. One factor that is of particular interest is the extent to which the PPE colour 'blends' with the background colours of vehicles.

The purpose of the colour board study was to gather data on the relative ease with which the yellow and orange PPE materials could be seen against four background colours (yellow, orange, white, and silver). Data were collected from drivers after they had taken part on their track drive, using an in-situ colour board containing all possible PPE/background combinations for comparison. By collecting data from participants while they were still in the car (using full beam headlights at night) it was possible to maintain a degree of ecological validity, while the design of the board made it possible to maintain some control over possible positional effects (especially related to the uneven spread of light from the car headlights).

6.2 Method

Participants

All participants who took part in a track trial took part in the colour board study, although again some data are not included due to coding errors or a small number of participants who were unable to complete both the track trial and colour board trial. This study was conducted immediately after the track trial.

Procedure

When participants reached the board, the car was parked facing it at a distance of around 10m (night time data) and around 12m (daytime data). Car headlights were on full beam during the night time trials to give a more even spread of light than would have been obtained by dipped beam. Participants were then asked a series of set questions all of which asked them to give subjective estimates of which PPE colour dots were most visible relative to other comparison dots on the board. The questions were worded so that they corresponded to a standard system that labelled the eight dots (four yellow and four orange) 'A, B, C, D, W, X, Y and Z' and the four backgrounds (yellow, orange, silver and white) '1, 2, 3 and 4'. This was partly to ensure that the questions still made sense to the participants at night, when colour is relatively less clear. It also meant that whatever orientation the board was in (see Appendix H) the questions asked were identical for each participant; later on, the data from the questions were combined with information on which board orientation was used with each participant, to map the questions onto the respective PPE colour dot/background combinations. The important point is that all participants were asked questions designed to elicit the following comparative ratings:

1. Which dot/background combination leads to the easiest to see dot?
2. On which background is the yellow dot easiest to see?
3. On which background is the orange dot easiest to see?

¹¹ From the use of consistent, realistic, scenarios.

4. On a given background (yellow, orange, silver, white) is the yellow or the orange dot easiest to see?
5. Which is the easiest background to see?

After this procedure, participants were driven back to the main TRL building for their post-drive interview.

Design

The responses to the eight questions (questions 1, 2, 3 and 5 above were asked once each, and question 4 was asked once for each of the four coloured backgrounds) resulted in categorical data; each person was forced to choose one of the options given for each question. These categorical data were used for the analyses reported in Section 6.3.

The board was rotated and the sides changed such that approximately an equal number of participants (both at night and during the day) saw the board in each possible rotation/side combination, meaning that differences in lighting from headlights, and positional preference effects would be spread across all participants; therefore any visibility differences reported should be due to the colour/background combinations alone.

Board and equipment

The colour board used in the second track trial consisted of a double-sided board with four 'petals', and can be seen in Figure 6-1. A detailed description of the board can be seen in Appendix H.



Figure 6-1: Colour board

6.3 Results

Night time data

The first question of interest for this task is which dot/background combination gave rise to the highest number of responses for the question "which is the easiest dot to see overall?" Figure 6-2 shows these data.

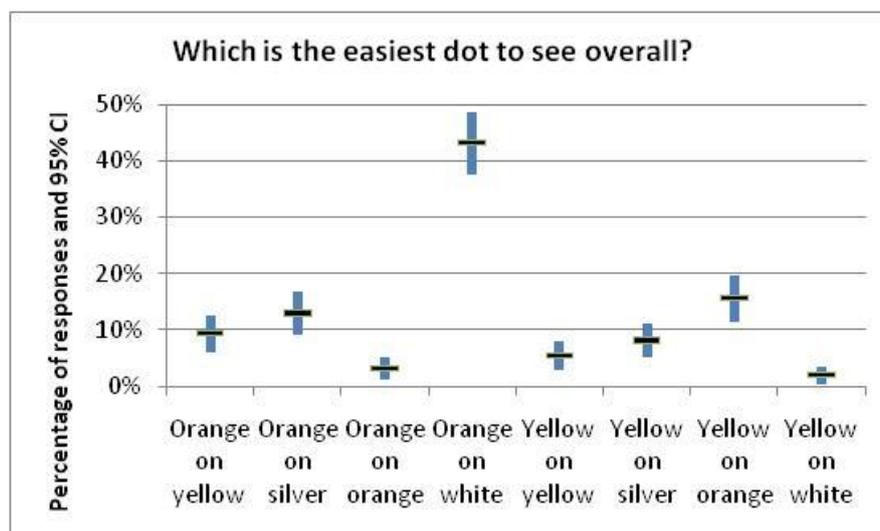


Figure 6-2: Percentage of respondents (with 95% confidence intervals) picking each dot/background combination as the 'easiest to see' – night time data.

The data show that by far the 'easiest to see' combination, according to the subjective judgements given in the night time conditions was the orange dot on the white background.

An analysis of responses by category of dot and background colour was conducted using a general loglinear multinomial model. Fitting just main effects for the dot colour (orange or yellow) and background (orange, yellow, white or silver) did not generate an adequate model (Likelihood ratio=131.2 on 3 df $p < 0.001$). Hence a fully saturated model including the interaction between dot and background was required.

The model showed that relative to the yellow dot on silver background (the base level considered):

1. Significantly lower numbers of people chose the orange dot on an orange background and the yellow dot on a white background as the 'easiest to see'; and
2. Significantly more people rated the orange dot on a white or silver background, or the yellow dot on an orange background as the 'easiest to see'.

The pattern of data for the other questions was in agreement with these findings:

1. The yellow dot was easiest to see when on the orange background.
2. The orange dot was easiest to see when on the white background.
3. For yellow, silver and white backgrounds the orange dot was easiest to see, while for the orange background the yellow dot was easiest to see.

Finally, the white background was the one most often rated as the easiest background overall to see, as shown below in Figure 6-3.

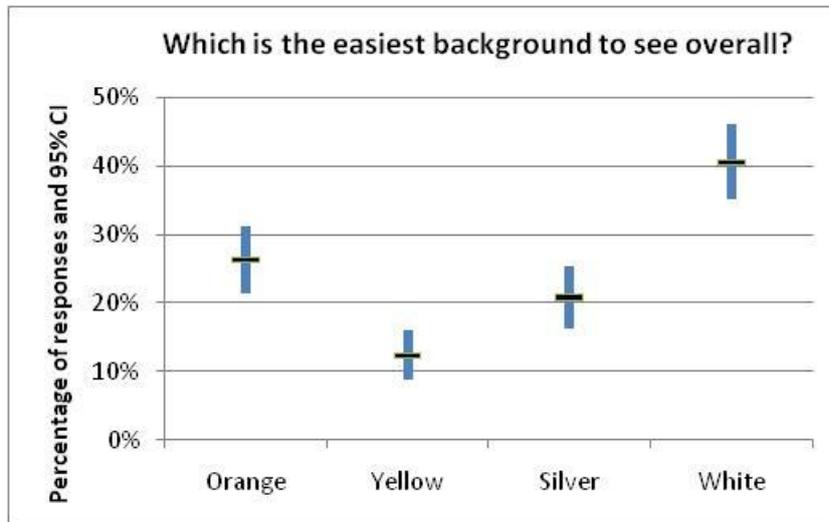


Figure 6-3: Percentage of respondents (with 95% confidence intervals) picking each background as the 'easiest to see' – night time data.

Daytime data

Figure 6-4 shows the findings for the question “which is the easiest dot to see overall?” from the daytime data.

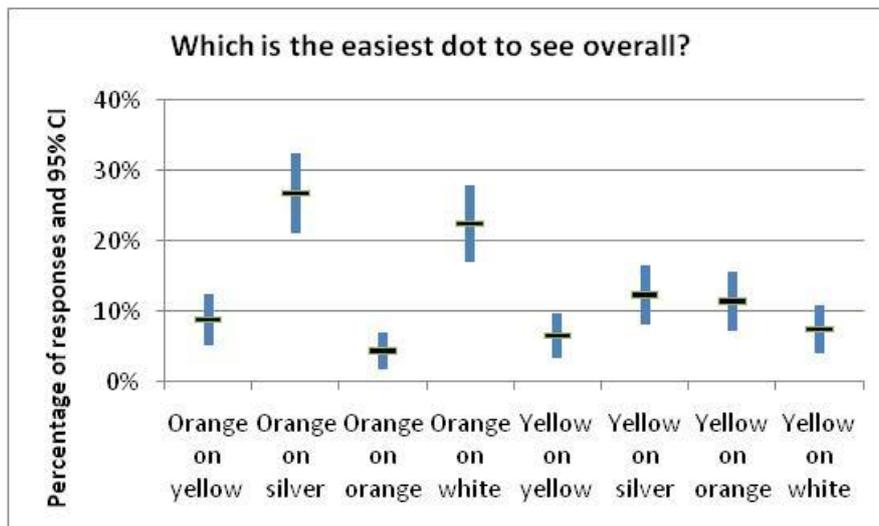


Figure 6-4: Percentage of respondents (with 95% confidence intervals) picking each dot/background combination as the 'easiest to see' – daytime data.

As with the night time data, an analysis of responses by category of dot and background colour was conducted using a general loglinear multinomial model. Fitting just main effects for the dot colour (orange or yellow) and background (orange, yellow, white or silver) did not generate an adequate model (Likelihood ratio=25.5 on 3 df p<0.001). Hence a fully saturated model including the interaction between dot and background was required to explain the response distribution.

This model showed that relative to the yellow dot on white background (the base level considered), significantly more people rated the orange dot on a white or silver background, as the 'easiest to see'; no other differences were statistically significant.

The number of people who rated each background as 'easiest to see' did not differ significantly by background colour. These data are shown in Figure 6-5.

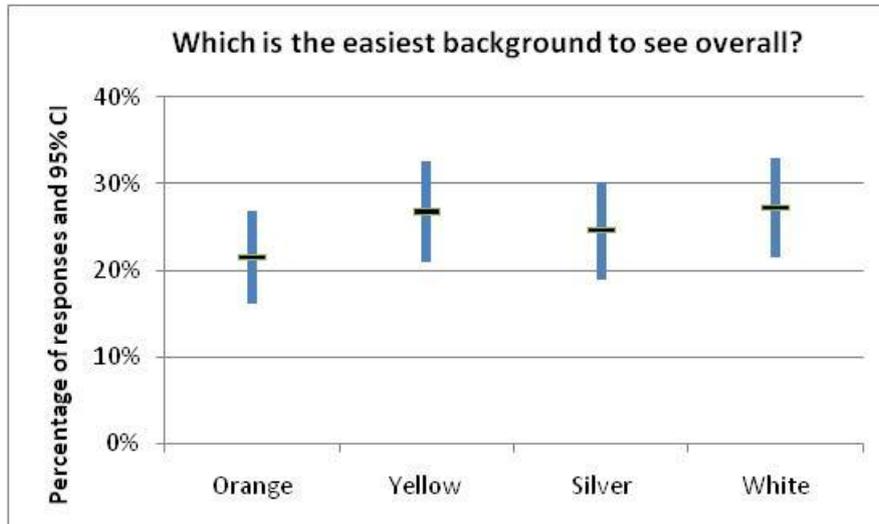


Figure 6-5: Percentage of respondents (with 95% confidence intervals) picking each background as the 'easiest to see' – daytime data.

7 Colour Vision and Deficiencies

7.1 Purpose

When considering which PPE colours and combinations might have different conspicuity (and therefore safety) impacts it is important that any possible differences in outcomes for those with colour deficient vision are taken into account. Separate analyses of the track and colour board data were undertaken for those participants who showed evidence of colour deficient vision, as evidenced by their responses to the Ishihara's tests for colour deficiency (Concise Edition, 2008), although these tests were not carried out under controlled conditions and so are indicative only.

Participants were defined as having some kind of colour vision deficit if they scored 7 or fewer on the vision test.

7.2 Colour Blindness – Implications

Normal colour vision is described as trichromatic, where colour matching can be achieved by mixing three colours, although there is considerable variance in that ability between normal trichomats.

The main types of colour deficiency, and incidence within Euro-Caucasians, are:

- Deuteranomaly; 5% of males, 0.4% of females
- Protanomaly; 1% of males, 0.2% of females
- Protanopia; 1% of males, 0.2% of females
- Deuteranopia
- Tritanopia
- Tritanomaly

The percentage of males affected varies within ethnic groups (Delperro et al., 2005), typically:

- 8% of the male Euro-Caucasian population
- 4% Asian male
- 2% African male

Two main types of defect can be described: red/green and blue/yellow. The red/green defects occur within the dichromatic and trichromatic forms of colour deficiency, while blue/yellow defect is the within dichromatic.

7.3 Simulated images

The images in Figure 7-1 illustrate what those people with various types of colour deficient vision are believed to perceive when observing the different types of PPE used in the study. When shown the appropriate pair of images, a member of TRL staff commented:

"Are those pictures different?"

These images are of plain colours; two members of TRL with colour deficient vision noted that they are able to identify 'fluorescent' colours during daytime. However, the fluorescent aspect of PPE background material is not apparent at night as this relies on ultraviolet component of sunlight.

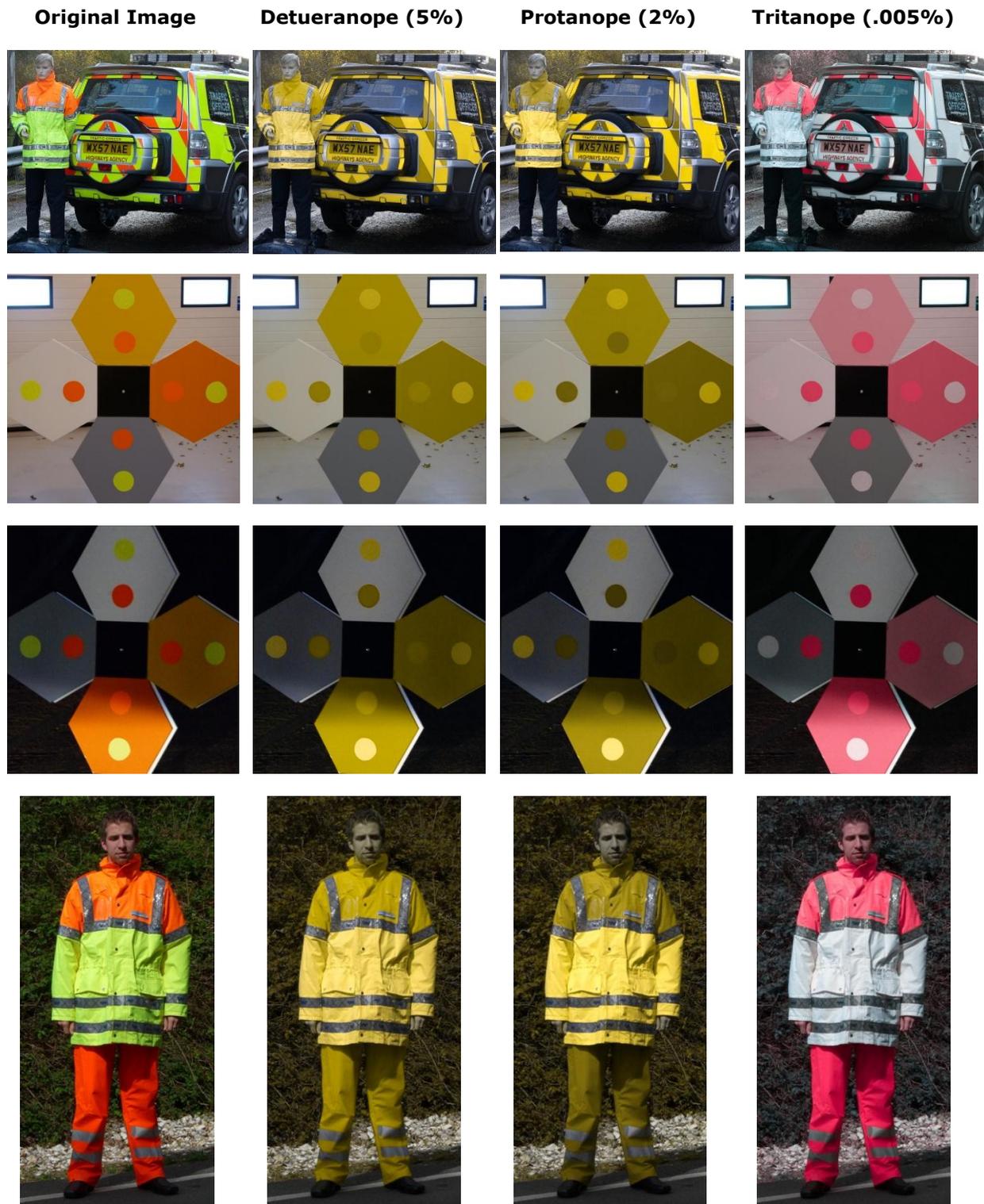


Figure 7-1: Simulated images from the Visolve web-based software (used with permission from Ryobi System Solutions)

Note that the protanomaly and deuteranomaly types are caused by dysfunctional cones (photoreceptors within the eye, mainly responsible for colour perception), so a variation in individual colour discrimination is possible between individuals.

7.4 Trials Colour Board Results

The low numbers of participants identified as colour deficient did not allow a formal analysis of track data for this sub-group, either during the night time or daytime conditions. However, the results for the colour board experiment were analysed and a comparison made between these identified with and without colour deficiency, for both daytime and night time data.

The very small numbers of participants involved mean that the results need to be treated with caution; the trial was not originally designed to test for the effect of colour vision deficiencies on any of the tasks.

However, the results indicate that broadly speaking those participants with colour deficient vision behaved in the same way as those with 'normal' colour vision. For colour deficient participants the ratings of how easy it was to see the different dots and backgrounds on the colour boards were not any different to the ratings of those participants with normal colour vision.

8 Discussion

8.1 Road worker opinions

The consultation exercise revealed a range of assumptions held by road workers regarding conspicuity. Some of these such as over-estimation of distance at which they can be seen and belief that they are more visible with hi-viz uniforms (especially at night) may lead to them putting themselves at risk when working on or near the road. Road workers assume that drivers should bear much of the responsibility regarding their safety and also fail to appreciate some of the limitations of their own high visibility equipment, especially for night time conspicuity. This is not unexpected given previous research into pedestrian conspicuity and indicates that there is a potential advantage to be gained through training and educating road workers about the mechanisms by which their conspicuity is increased or decreased, during the day and the night (see next section).

For example Tyrrell et al. (2004) were able to show that a specific educational intervention was able to improve such calibration in students (who also over-estimated their conspicuity in a track study). The intervention was specifically designed to make students aware of the mechanisms by which different types of PPE can work to improve conspicuity and when such mechanisms are not able to help; for example at night the retro-reflective materials on PPE are highly effective, but much more so when cars are using full-beam headlights. However, drivers may not be using full beam while passing road works or incident scenes, so that additional effectiveness will not be obtained.

8.2 Overall detection distances under attention conspicuity instructions

The most important finding from the current study relates to the absolute distances at which the mannequins were mentioned in participants' commentaries on the track study. Although these distances cannot be assumed to relate exactly to detection distances on the road, it is likely that they are a reasonable estimate, given the efforts taken to keep the scenarios consistent and realistic. Indeed if anything they are likely to be overestimates of real-world detection distances since the scenarios on the track were less complex than those seen on real roads. This is not least because of the lack of other traffic, and the fact that participants were being driven in the study (rather than having to drive themselves) meaning that they would have been able to pay more attention to their commentaries in the study than would have been true in real-world driving.

With these caveats, it is worth reflecting on the average time before the scenarios at which the mannequins were mentioned in commentaries (where this is taken as an estimate of detection time):

1. In Scenario 1 the detection distances (at 40mph) ranged from 25 to 45m at night, and from 110 to 150m during the day.
2. In Scenario 2 the equivalent distances ranged from 50 to 70m at night, and 106 and 141m during the day.

On the basis of these findings, it is clear that if participants' commentaries reflect their attention while driving, road workers should not assume that their fluorescent and reflective PPE is making them 'visible' to drivers at the kinds of distances suggested from previous work that uses 'search' conspicuity instructions. This is especially true under night time conditions. Rather, they should assume that the distances at which drivers see them and are likely to be short, and should behave accordingly.

The extremely short detection distances at night are likely to be due to the fact that the trial vehicle was not using full-beam headlights; this was designed to mimic the

conditions in everyday driving, in which it is likely that when driving through road works or next to incidents, most vehicles (most of the time) will not be using full beam headlights.

Dipped beams tend to project their light towards the nearside of the lane ahead, so are unlikely to illuminate road workers towards the offside, such as those placing signs on a central barrier. Also, the maximum height that light is projected by dipped beam is restricted to prevent dazzle to oncoming vehicles, so the retro-reflective areas of PPE above that height will receive limited illumination. This has an implication for any road worker uniform which does not include lower-leg retro-reflective or combined performance material (Blomberg, Hale & Preusser, 1986) and suggests that ankle retro-reflective markings may be useful.

The higher detection distances for Scenario 2 may have been due to the fact that, in this scenario, there were three mannequins rather than two. Alternatively, it is possible that the greater separation between the flashing beacons (on the vehicle) and the mannequins stood near the vehicle resulted in these mannequins being less susceptible to 'glare' associated with the beacons. This is of particular concern when considered against the context of workers' beliefs that their safety is heavily reliant on the visibility of their vehicle, even that their own conspicuity is not important (so long as something attracts the drivers' attention). It was not uncommon for road workers to believe that by being near their vehicle the light helps to illuminate them, rather than mask them.

Working practices that place the worker in close proximity to highly conspicuous vehicles may hinder the conspicuity and recognition of road workers by drivers. This may occur in low light conditions when the lighting and/or retro-reflective material cause glare for drivers, or when they are brighter than the worker's retro-reflective material. In daylight, the worker's PPE colour may have a similar colour to, or insufficient contrast from, the vehicle colour scheme, as identified by the colour board element of the current study.

When the lighting systems were in use there were variations for the accuracy of recall participants had of mannequins within both night time scenarios. Within the Traffic Officer scenario there was a noticeable change in participants correctly remembering the mannequin located at the rear of the TO vehicle. In the TTM vehicle scenario identification of mannequins to the rear of the vehicle was improved for both yellow and orange PPE, but the most noticeable improvement was for the mannequin located to the trials vehicle's offside across the roadway from the TTM vehicle. Improvements in the correct identification of the mannequins may have implications for the use of lighting within road works and during times when street lighting is switched off.

In daytime, the use of whole-body conspicuity from the wearing of fluorescent jacket and trousers seems likely to give earlier detection by approaching road users as the wearer provides a larger physical area for approaching drivers to notice. Also, the wearer may aid the approaching driver's earlier recognition of a 'person' shape. Data from the current daytime study (Scenario 1) are consistent with this interpretation, although again should be treated with caution as the observed differences do not reach statistical significance and do not provide categorical evidence.

Both these night time and daytime whole body conspicuity aspects are particularly relevant to the HA's Traffic Officer Service, where the standard corporate uniform allocation includes dark trousers with no retro-reflective material on the lower leg.

8.3 Differences between colours and designs of PPE in detection distances

Overall there was almost no data from the track trial to suggest that any one PPE colour or combination is generically 'better' than any other. There was a slight trend in the data from Scenario 1 during the night time 'lights on' condition to suggest that orange

PPE was leading to longer detection distances, although no differences were statistically significant. For Scenario 2 during the night time 'lights on' condition, the trend was that yellow PPE led to longer detection distances, although again no statistically significant differences were found. During the daytime for both scenarios, the trend was again suggesting a slight advantage for yellow PPE (including the HA multi-colour jacket with yellow trousers), but again the lack of statistically significant effects means that no firm conclusions should be drawn.

Interestingly, when considering the order of detection distances for the different PPE colours in daytime conditions, it is worth noting that the order corresponds to the luminance levels present in the PPE (see Appendix I). It is possible that the luminance levels present in the PPE were responsible for their overall daytime conspicuity, assuming that contrast was relatively constant.

Previous unpublished research for HA has suggested that, due to the continued presence of hi-viz clothing to the prescribed standard, the pattern of BS EN471 retro-reflective stripes has effectively become part of drivers' knowledge base, consequently increasing its conspicuity through the influencing of driver expectations. It is possible that the ubiquitous use of fluorescent yellow road worker PPE has led to drivers having a subconscious understanding that 'fluorescent yellow = person'. Identification by drivers of a 'person' in an uncluttered environment can be aided by bio-motion, when an observer recognises human movements. For Traffic Officers (who are more likely than road workers to be in an uncluttered environment) this recognition could be helped by lower leg retro-reflective material. However, the bio-motion effect ceases when the person stops moving.

8.4 PPE colour / vehicle background combinations

The data from the 'colour board' study showed that at night, by far the most 'visible' combination (as rated subjectively) was orange PPE material against a white background. The next most visible combinations were orange on silver and yellow on orange. These findings are likely to be due to the contrast between the PPE material and backgrounds, with colour (at night) likely to play a secondary role in conspicuity. White was rated the most visible background at night.

Ratings of the visibility of different combinations of PPE/background materials, and the fact that the mannequin stood behind the road works vehicle in Scenario 2 was the least well-recalled (implying it was the least well-noticed), especially at night, suggests that some PPE may cause 'blending' with the background, if that background contains large blocks of colour (in this case the vehicle back) of a similar hue and luminance to the PPE, completely covering the silhouette of the PPE.

During the daytime, 'orange on silver' and 'orange on white' were by far the most likely to be chosen as most visible. There was no difference in the visibility ratings of backgrounds. However, there are concerns that silver would not be a suitably conspicuous vehicle colour to make the vehicle more visible. Silver may not provide sufficient contrast against roadside infrastructure and may be less visible in poor weather conditions.

Taken into consideration with the colour deficiency test results from the colour board, these findings suggest that the PPE colour is not as important in conspicuity as the contrast between the PPE and its background. It is not feasible for road workers to change their uniform to provide maximum contrast with their background at the time, but this finding must be considered if any case is made for mandating vehicle colour for road workers, and should be considered when specifying high-visibility uniforms and vehicle colour schemes for the Traffic Officer Service.

For yellow PPE, the optimum was yellow on orange. This corresponds to the current arrangement for the HA salting vehicle fleet, suggesting that any future changes to PPE

colour away from yellow should consider that conspicuity of salting vehicle personnel as a special case.

8.5 Expectancy models

The interviews with participants tended to show a great deal of variability in peoples' 'expectancy models' regarding the presence (or absence) of road workers around stopped vehicles with flashing beacons. There is by no means a unanimous expectation of seeing 'people' when observing a vehicle with flashing amber lights stopped at the roadside, and the location where people might be expected is also variable.

Although this may be due to a lack of understanding of the work (whether planned or incident response) that happens on the HA network, it is possible that over-use of warning beacons has altered road users' expectancies. The HA may wish to consider whether there could be benefits to be gained from restricting the use of warning beacons to situations where there is a raised level of risk to both approaching drivers and workers at the scene and ensuring that those beacons used are appropriate to the circumstances.

8.6 Participants with colour deficient vision

Although the study was not originally designed with the intention of studying colour deficient vision, it was possible to do an informal check on those people recruited who happened to have some kind of colour vision deficiency as measured by appropriate test. The data from the colour board suggested that these individuals did not behave any differently to those with normal colour vision in terms of their subjective ratings of visibility of PPE and background combinations.

9 Conclusions

9.1 Road workers are not highly conspicuous, even in hi-viz PPE

The first conclusion of this report is that the detection distances of mannequins within realistic scenarios involved under 'attention conspicuity' instructions were very much smaller than those typically seen in the 'search conspicuity' literature. In other words, under more naturalistic viewing conditions and with a more naturalistic set of instructions, road workers are not very conspicuous.

It is highly likely that road workers in general are not aware of this; anecdotal accounts known to the project team suggest that often road workers have a perception that they are highly visible from great distances, even at night. In effect, road workers are likely to over-estimate their actual levels of conspicuity. Some kind of educational initiative might be of benefit to remedy this situation, although care should be taken to ensure that such an intervention is designed to focus on the actual mechanisms by which different types of PPE can help visibility and in which circumstances; sound evaluation of the outcomes of such an intervention is also essential, to ensure that effectiveness is quantified, and unintended adverse effects (e.g. overconfidence) are ruled out.

9.2 Drivers do not necessarily expect to see road workers

Participants in this study did not consistently report the expectation of encountering road workers in their everyday driving. More than half the participants reported that they would not expect to see people where a vehicle with flashing lights is stopped at the roadside.

Again it is likely that some kind of appropriately designed educational intervention may be effective in changing this mindset. Interestingly in Scenario 1 in the current study, during the night time conditions (those which were most challenging according to the extremely low detection distances) there is some evidence that those participants who were actively looking for people at the scenario detected the mannequins earlier than those who were not. Thus one possible aim of any public education might be to establish within drivers a desire to actively search for people at such scenarios in everyday driving. This could be further expanded by inclusion of specific road worker examples within the DSA's Hazard Perception and Theory tests.

9.3 There was no obvious 'overall' impact of different types of PPE on detection distance

There were no firm data in the current study to suggest that any one PPE colour or design granted any advantages in conspicuity over any others, although there were some (statistically non-significant) trends in the data. For example, when additional trackside lighting was switched on yellow PPE seemed to have a slight advantage in one scenario at night, while orange seemed to have a slight advantage in another scenario at night. This suggests that all PPE is to some extent advantageous; the key issue is that, across the board, PPE is not likely to be as advantageous as those people wearing it believe it to be.

There may be some situations in which specific colours of PPE might be beneficial. For example, the data from the colour board suggest that orange PPE against a white background at night is more visible than other combinations.

9.4 Ankle markings and fluorescent trousers would be advantageous

The results of the daytime Traffic Officer scenario (see Section 3.4) suggest that daylight conspicuity could be improved by the use of yellow fluorescent trousers by Traffic Officers.

Since the current HA uniform does not have any ankle-markings, night time conspicuity should benefit from fitting of retro-reflective materials to the ankles of this PPE design, particularly since low-beam headlamps will not effectively illuminate retro-reflective material on a jacket.

9.5 White may be the most appropriate vehicle colour at night, and orange PPE against white vehicles may be the easiest to see

Another issue is that of vehicle colour. In the current study the only data that bear on this issue are the data from the colour wheel experiment; these data suggest that white is (at night) by far the most visible colour in the situations used in this study. Although it is not advisable to reach a firm conclusion from the colour wheel study with respect to vehicle colour, the findings do at least suggest that white may be the best overall colour to consider, when day and night time visibility is taken into account. The data also suggest that orange would provide the best colour PPE for occasions when workers are stood in front of a white vehicle.

However, this research was undertaken with panels of colour rather than with vehicles and PPE. Before any wholesale change to vehicle and PPE colour is recommended, further research should be undertaken to replicate the findings in naturalistic settings and establish which colour different combinations are advantageous or detrimental to conspicuity. It should also be noted that not all road workers remain in close proximity to vehicles while working.

Should a mandated change to vehicle and PPE colour be anticipated for workers on the HA Network, this should be planned carefully to avoid any 'blending' issues during any changeover; for example: while the combination of white vehicles and orange PPE may be easiest to see, the combination of yellow PPE against white vehicles rarely selected by participants as the easiest to see and could potentially lead to 'blending', so reducing road worker conspicuity.

10 Recommendations

The key recommendations arising from this report are presented in three sections. First, general actions, then those specific to the Traffic Officer Service and finally those specific to other road workers.

10.1 General actions

Educate road workers and Traffic Officers about their actual levels of conspicuity

The key recommendation of this report is that all people who work on or around roads should be educated as to the distances at which it is likely they are being detected, particularly by drivers who are not specifically searching for them.

The information described in Section 2 of this report has established road workers' knowledge of their conspicuity and their over-optimism regarding detection distances, especially at night. An appropriate training and education package should be designed, following the principles outlined in Section 9.1, with the specific intention of ensuring road workers have a realistic understanding of their actual conspicuity within their working environment.

Workers should also be made aware of the difficulties approaching drivers may have identifying them when they are in close proximity to works vehicles, particularly those vehicles fitted with high-visibility colour schemes and/or displaying warning beacons.

Educate drivers with respect to the likelihood that road workers are present in the kinds of scenarios encountered in everyday driving

Campaigns targeting drivers' knowledge and understanding of road worker safety, such as the current 'THINK' campaign, should include reference to the likelihood of road workers being present, and their relative lack of conspicuity, especially at night, even when wearing high visibility PPE. Careful management of how messages are delivered will be needed to ensure expectancy in drivers is raised appropriately. For novice drivers, the DSA Hazard Perception and Theory tests could include specific road worker examples.

10.2 Actions specific to the Traffic Officer Service

Adopt ankle retro-reflective materials

Retro-reflective materials should be fitted to the ankle areas of TOS uniforms, to aid conspicuity at night when in the vicinity of cars using dipped headlights.

Adopt fluorescent trousers

Traffic Officer uniform should adopt the use of yellow fluorescent trousers to improve daytime conspicuity.

10.3 Actions specific to other road workers

Consideration should be given to the specific circumstances under which different colours of PPE might be useful

The data do not support the notion that a change to orange PPE is required 'across the board' to increase safety. However it should be considered whether there are some specific situations in which the combination of orange PPE and white vehicles, or yellow PPE against orange vehicles for the HA salting vehicle fleet, may be beneficial to road worker safety.

Consider the use of white vehicles

The data suggest that white vehicles are more visible than other colours at night, and the combination of white vehicles and orange PPE may be easiest to see. Should a mandated change to vehicle and PPE colour be anticipated for workers on the HA Network, this should be planned carefully to avoid any 'blending' issues, such as the combination of yellow PPE against white vehicles which could reduce road worker conspicuity.

Acknowledgements

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Visolve colour deficiency representations:

<http://www.ryobi-sol.co.jp/visolve/en/tryonweb.html>

Appendix A TRL test track

TRL's Test Track is located on a secure secluded site providing a carefully controlled and safe operating environment. The track consists of five different sections, all of which can be operated independently of each other.

The test track is largely bordered by mature coniferous woodland, restricting views from outside of the site. Participants did not get sight of the scenario while entering the site, nor could they interact with participants who had completed the trial.

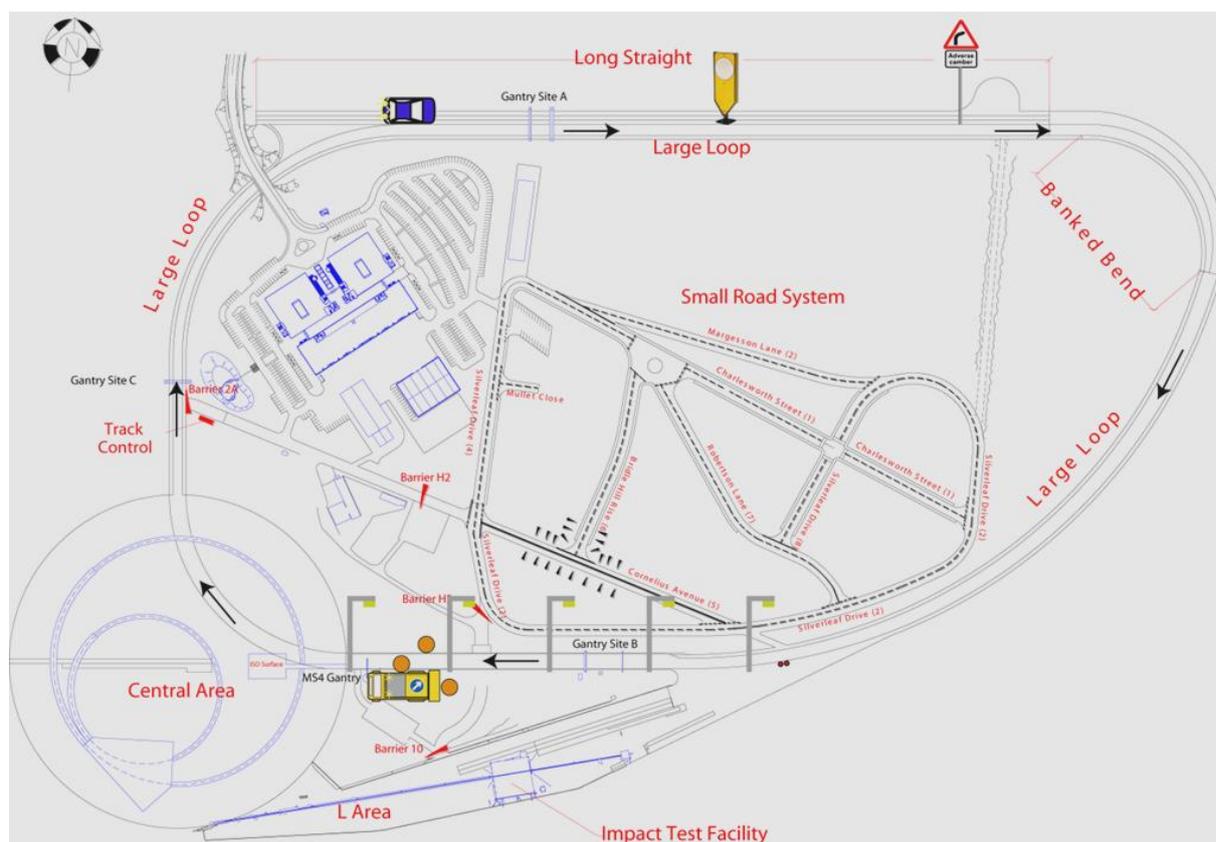


Figure 10-1: TRL Test Track, with locations of 'commentary' items and scenario indicated

Trial drives commenced at the main building, commentary started at track control. The trial 1 route used the Large Loop, travelling clockwise. Trials scenarios were set up on the 'Motorway' section on the South side of the Large Loop, with additional practice items set up on the 'Long Straight' section on the North of the Large Loop.

The 'motorway' section is straight for approximately 260m, allowing participants a good (approximately 400m) view of the scenario during their approach. The section is 10.5m wide with markings indicating three lanes, bordered by a narrow shoulder and impact barriers.

Colour panel comparisons, took place on the Small Road System street during 'Night Time' trials, and on the Central Area for 'Daytime' trials.

Participants were returned to the main building for the post-drive interviews. During the interview participants were asked whether they had seen the scenario or its flashing lights prior to the trial drive, none said that they had.

Appendix B Instructions for training video

Trials participants were shown a short training video to introduce the concept of giving a commentary during the trials drive.

B.1 Presenter's script:

The training video was introduced by a member of staff:

Thanks for coming along to take part in the night time hazards trial. I will explain what you'll be taking part in this evening:

During the first part you'll watch a short video, then be driven around a track to look for hazards.

During the second part of the trial you'll be in our small roads network, you'll be given details when you get there.

You'll then have a debrief and a quick eyesight test; do you have your glasses or contact lenses if you need them for driving?

This video explains what we'd like you to do on the track.

Show Video

When the first two clips are running that these are examples without commentary and that in a minute they will be shown again with examples of the kind of commentary we expect participants to do tonight on the track.

Is anyone unsure about what they need to do or say?

Repeat the main video script elements:

Remember there is no 'right or wrong' – this is all about you telling us what you see, in very simple commentaries.

Remember: "See – Say"

I'll now be taking you to wait for a free car and driver to take you around the test track. You will need your glasses or contact lenses for this trial.

B.2 Video script

Two training videos were prepared. The two videos followed an identical format, introducing the concept of 'commentary', showing examples of typical items likely to be encountered on public roads, then longer clips with an example commentary of the type required from participants.

The following script was used for voice-over through the training video.

Thank you for helping with TRL's Night Time Hazards trials.

This evening you will be taking part in two trials on the TRL test track, and then a short debrief which will include an eyesight test. For the duration of the trials and the eye test, please wear your glasses or contact lenses if you need them for driving.

This video will cover what we would like you to do during the first on-track trial. You'll be given details of the second trial later.

You may be aware of driving 'commentaries', perhaps from watching police drivers on television, or from taking 'advanced' or 'defensive' driver training.

We would like you to do something similar while being driven around the test track.

However, we'd like you to do something simpler.

Every time you see something which attracts your attention, and that you think a good driver would notice while driving, we would like you to say out aloud what it is you see as soon as you can.

You can comment on anything, no matter how inconsequential it might seem.

Remember: See – Say

Here are some examples . . .

Commentary given was single-word wherever possible, and 'developing', adding further detail when the scene changed or becomes clearer.

You can comment on anything you think a good driver would notice while driving, no matter how inconsequential it might seem.

Remember: See – Say

If you have any questions about what we'd like you to do, please ask a member of TRL staff. From here, you will be taken to wait for a test car to become free. In the car with you will be a driver and a TRL researcher. The drive will be video recorded for later study.

Thanks for taking part.

B.3 Video screenshots

The following screenshots show important elements of the video voice over as they were emphasised during the presentation and examples of the items which participants saw later during the trials as 'practice items' (those illustrated are from the 'Night Time' trials) for the example commentary given.



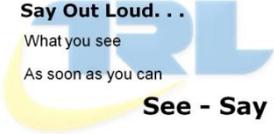
Look for . . .
Something a good driver would notice
Which attracts your attention



Page 2



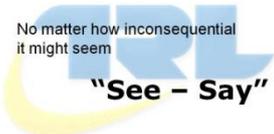
Say Out Loud . . .
What you see
As soon as you can
See - Say



Page 3



No matter how inconsequential
it might seem
"See - Say"



Page 4



Appendix C Track trial instructions for drivers

The following instructions were given to drivers taking part in the trial (Night Time example given, minor modifications made for Daytime):

Ensure all passengers are seated comfortably and wearing seatbelts, and that the test candidate has a good view ahead.

Start drive from Western end of Crowthorne House (restaurant end), facing South (towards ITF). Maintain lights on dipped beam

Travel to track control and stop.

Enter Test Track Large Loop

Turn Right, move into left lane (of 2)

Accelerate briskly to 40mph (set cruise control)

Continue at steady speed of 40mph

Maintain position in second full lane from right (offside) of track along Long Straight

Maintain speed and position in lane through banked turn

After exit from banked turn, continue in lane until marker cone group

Change course to centre lane (of three) along Motorway section

When past the main scenario (at entry to Central Area), gradually reduce speed to leave Large Loop at Track Control. Use indicators.

Travel at max 20mph to marked position for Colour Boards trial.

Stop alongside parked test vehicle, keep engine running.

Switch lights to full beam for duration of questioning

Leave SRS,

Return to start (max. 20mph). **Do not use full beam in the car park.**

NB: Drivers must be track approved, and be fully aware of the track procedures manual.

Deer: If you see any deer, reduce speed and radio in to warn other drivers

Appendix D Track trial researcher instructions

Researcher to remind test candidate of commentary requirements, as in training video:

"Every time you see something which attracts your attention, and that you think a good driver would notice while driving, we would like you to say out aloud what it is you see as soon as you can."

You can comment on anything, no matter how inconsequential it might seem.

Remember: See – Say

"Start commentary when the car moves off, and please speak up for the microphone"

"Are you ready to start?"

Remind candidate:

"Begin your commentary as soon as the car begins to move"

Researcher **STARTS CAMERA** (stating participant number for camera)

e.g.:

"Sign"

"Car with flashing lights"

"Some cones on the side of the road"

After final scenario, researcher says:

"Thank you. That's the end of the first trial, you can stop commentating."

Appendix E Uniforms/PPE used for track trials

Each of the two scenarios used different combinations of uniform or PPE, all meeting the requirements of BS EN 471. These were combinations were displayed using mannequins, ensuring that the position of each variation was consistent throughout the trials and that there were no 'bio-motion' movement effects which might attract the participants' attention. The number of participants viewing each colour option was balanced throughout the trials.



Figure 10-2: Realistic mannequins, as used in scenarios

E.1 Scenario 1: Highways Agency Traffic Officer Service

For this scenario, three colour alternatives were used during the night time trials:

1. Traffic Officer Service uniform jacket (two-tone orange and yellow) with dark trousers (no retro-reflective ankle bands)
2. Full fluorescent yellow jacket and over-trousers
3. Full fluorescent orange jacket and over-trousers



Figure 10-3: Three colour combinations used during Night Time trials

During Daytime trials this was increased to five alternatives by the addition of:

4. Traffic Officer Service uniform jacket (two-tone orange and yellow) with fluorescent yellow over-trousers (with retro-reflective ankle bands)
5. Traffic Officer Service uniform jacket (two-tone orange and yellow) with fluorescent orange over-trousers (with retro-reflective ankle bands)



Figure 10-4: Additional colour combinations included in Daytime trials

E.1.1 Micro-prismatic retro-reflective tape

HA Traffic Officer Service uniform jackets were obtained for use during the trials. These incorporate micro-prismatic retro-reflective strips, custom-made for the Highways Agency. To ensure consistency between the HA jackets and alternatives during night time trials, the glass bead retro-reflective stripes on the solid yellow and orange suits were over-laid with Reflexite GP440 micro-prismatic tape. The 'HA' branded reflective tape was manufactured by Reflexite, GP440 was the closest commercially available material.



Figure 10-5: -specific retro-reflective tape (left), Reflexite GP440 (right)

The HA-issue TOS jacket has an additional horizontal retro-reflective band around the body, just above the jacket hem, giving a total of three horizontal bands (BS EN471 states: "Jackets . . . shall have two bands of retro-reflective material". This additional band was not duplicated on the non-HA jackets.

E.2 Scenario 2: Road Workers

For this scenario, two colour alternatives were used. These were:

- Full fluorescent orange jacket and over-trousers
- Full fluorescent yellow jacket and over-trousers

Both suits incorporated glass-bead retro-reflective tape.



Figure 10-6: Two colour alternatives used in the 'Road Worker' scenario during both Night Time and Daytime trials

Appendix F Luminance comparisons

Two additional colour combinations were incorporated into the 'daytime' trials; therefore it was decided to obtain luminance images of all five combinations used in the 'Daytime' trials in order to determine whether relative luminance was an important factor in the identification of 'workers' in the scenarios used in the main trial and to compare with the results from the Colour Board trials.

Luminance images were obtained in both streetlit and fully dark conditions. For further detail of luminance images, see Appendix I.

F.1 Method

A black background was assembled. A car was positioned approximately 20m away with full beam headlights switched on, pointing towards the background. A luminance camera was placed on a tripod at a fixed distance from the background. As this experiment was interested only in the luminance of the uniform and not its retro-reflective stripes, the camera was positioned away from the vehicle so as to be outside the cone of retroreflectivity.

A member of TRL staff stood in a fixed position in front of the black background wearing each uniform in turn and a luminance photograph was taken. This arrangement is shown in below:



Figure 10-7: Visible (left) and luminance images

F.2 Analysing the images

Using markers on the backdrop, a rectangle was drawn on each image to give an average figure of luminance within this region, allowing an indicative measurement of the relative average luminance of each uniform. This does not highlight any areas which are particularly luminous or dark.

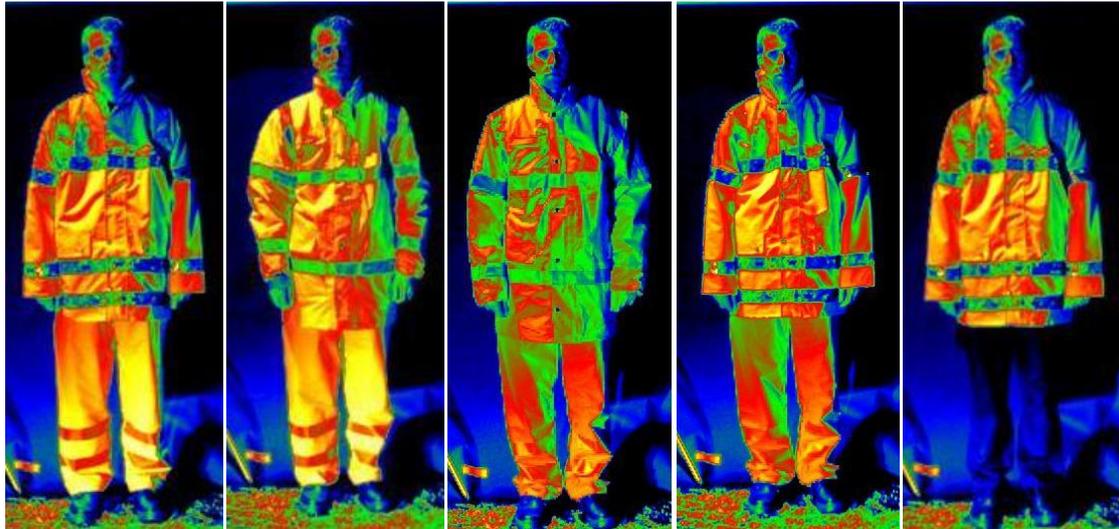


Figure 10-8: Streetlit; Yellow, Orange, HA/Yellow, HA/Orange, HA/Black



Figure 10-9: Headlamps only; Yellow, Orange, HA/Yellow, HA/Orange, HA/Black

F.3 Conclusions

It is important to note that, while the same arrangement of equipment was maintained within each lighting condition during the experiment, the lit and unlit conditions were carried out in different locations and the same conditions in terms of the relative positions of camera, vehicle and target object were not maintained exactly and the luminance values are indicative only. Therefore comparisons can only be made within each street lighting condition and not between the lit and unlit conditions. It is not a finding of this trial that road worker uniforms are more luminous in unlit than lit conditions.

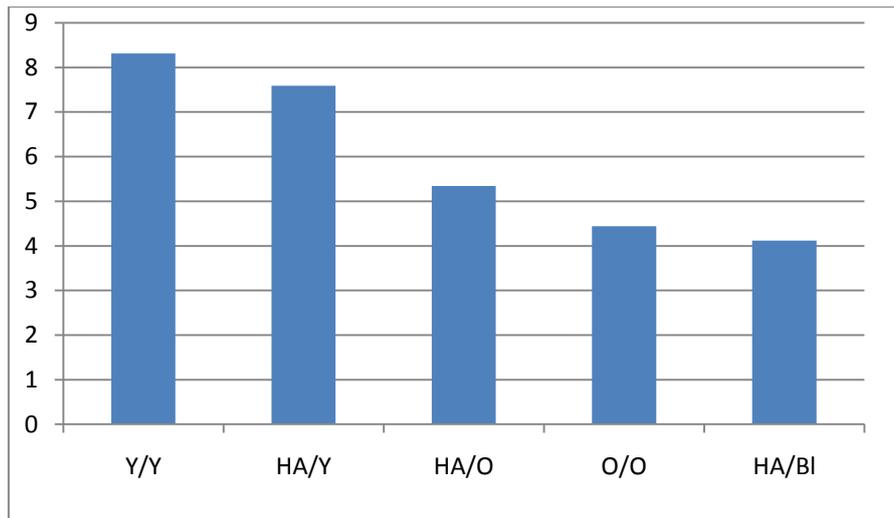


Figure 10-10: Relative luminance values, streetlit & headlamps

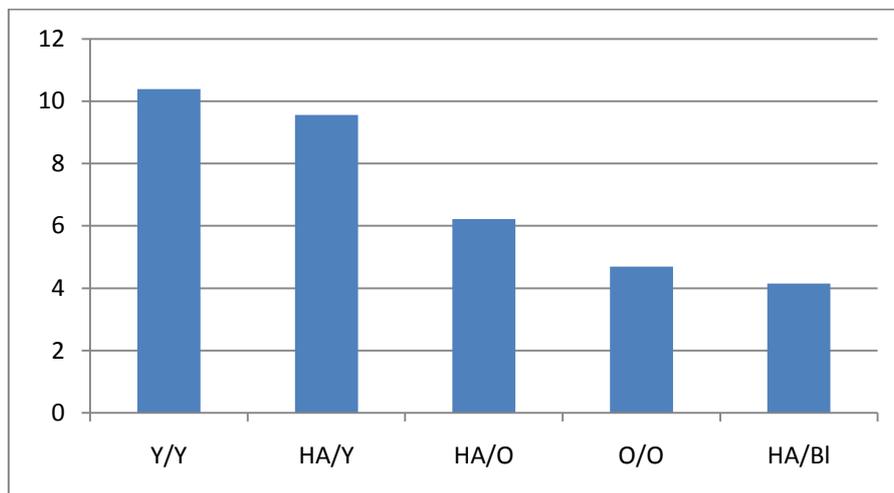


Figure 10-11: Relative luminance values, headlamps only

The graphs show clearly that yellow is more luminous than orange. The full yellow uniform is on the left, the next three options show a gradual increase in the use of orange instead of yellow (the HA Traffic Officer jacket is composed predominantly of yellow with an orange shoulder area). The final option on the right shows black trousers with the HA Traffic Officer jacket. It is noticeable that the overall luminance of this is little different to the full orange uniform; however this is due to the luminosity figures being an average for the whole area selected, with the brighter yellow area of the jacket balancing the significantly darker trousers.

Appendix G Scenarios

Two scenarios were used during the trials, each with specific vehicles positioned alongside the track and mannequins positioned relative to the vehicles. The MS4 gantry was not in use during the trial.

G.1 Scenario 1: Highways Agency Traffic Officer Service

A Mitsubishi Shogun, recently decommissioned from the Traffic Officer Service, was provided by the Highways Agency for use in the trials.

During the scenario the vehicle was parked in the 'fend off' orientation and displayed amber beacons and 'side' lights.

A further vehicle was positioned to represent a broken-down car, not displaying any lighting.

Two mannequins were positioned in the scenario:

- Adjacent to the rear nearside of the TOS vehicle
- Adjacent to the rear offside of the 'broken down' vehicle



Figure 10-12: HA TOS Scenario, showing vehicle and mannequin positions

G.2 Scenario 2: Road Workers

A typical Temporary Traffic Management (TTM) Impact Protection Vehicle (IPV) was obtained for use within the 'Road Worker' scenario and parked parallel to the roadside.

Equipment was displayed as if on the hard shoulder of a motorway, with the rear lighting board raised, 'blitz' strobe lights used, rotating beacons illuminated and the 'crash

cushion' lowered. The illuminated 'arrow' was not displayed, but the '610' sign was rotated to the 'right' orientation.

Three mannequins were positioned within the scenario:

- Adjacent to the rear nearside off the vehicle's crash cushion'
- Mid-way along the load bay, on the offside of the vehicle (as if removing a sign from the vehicle)
- Against the right hand side barrier, as if placing a sign frame on the central reservation barrier



Figure 10-13: Road worker scenario, showing vehicle and mannequin positions

G.3 Lighting equipment for track trials

Lighting was installed along approximately 400m of the 'scenario' section of test track using trailer-mounted, four-head systems. Each lighting head contained a 1000W metal-halide lamp, making a total of 4kW from each lighting trailer.

The lighting columns were raised to their maximum height of 9m and illuminated for half of each evening's trial drives.



Figure 10-14: Trailer-mounted lighting system

Appendix H Colour board trial



Figure 10-15: Colour board

The colour board used in the second track trial consisted of a double-sided board with four 'petals'. Each petal was painted with satin-finish paint, in one of four colours:

Lemon Yellow	BS381 No. 355 (as recommended by Chapter 8)
White	(as recommended by Chapter 8)
Light Orange	BS381 No 557
Silver-grey	BS381 No 628

On each of the 'petals', two disks of fluorescent material, one each yellow and orange, were fixed. These disks were cut from the appropriate PPE used in track trial 2 (Road Worker scenario). On one side of the board the disks were arranged with the yellow towards the centre of the board, on the other side with the orange towards the centre. Each side was denoted either 'Alpha' or 'Bravo' to aid set-up and recording. The board was free to be rotated about its centre point. At pre-determined intervals through each trial the board was rotated through 90 and turned so that either the Alpha or Bravo side was displayed. This ensured that responses to the questions asked were not entirely related to the relative locations of the coloured dots and backgrounds (and the resultant differences in luminance due to the uneven coverage of light from the dipped car headlights).

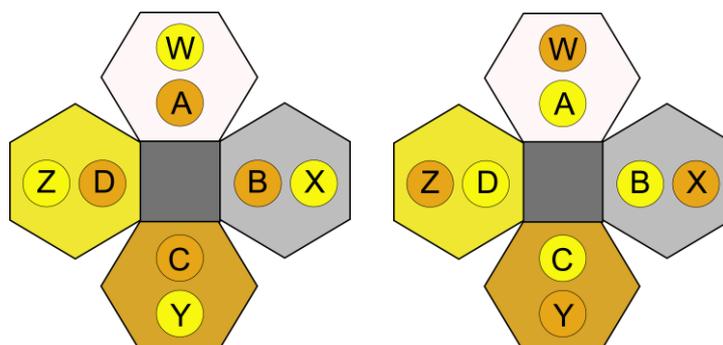


Figure 10-16: Alpha (left) and Bravo sides of colour board



Figure 10-17: Colour board in place on test track (small road system) during night time trials



Figure 10-18: Colour board in place on test track during daytime trials

Appendix I Luminance Images

In order to give an indication of light levels as seen by participants, both scenarios and the colour comparison board were photographed using a luminance camera. The images reproduced use 'false colour' in order to differentiate the levels of luminance within the scene. Due to the participants travelling past in a vehicle using dipped headlamps, the amount of light cast onto the scene would be varying constantly, as would the light returned to the participant by the retro-reflective material on the PPE.

The luminance scale on the images provided cannot be used to determine the luminance of lighting at the scene, whether the additional portable works lights or the vehicle beacons.

For the two track scenarios, a further image is provided which identifies more clearly the areas of each scenario which include the roadworkers. Within the area selected (shown in red) the luminance scale values alongside the images do not apply.

I.1 Context for luminance values

In order to give some context to the values on the scale adjacent to each image, and for figures included within the analysis:

- Luminance of 3 cd/m^2 is considered to be required on the white sections of street signs to be visible in an unlit area
- Luminance of 10 cd/m^2 is considered to be required on the white sections of street signs to be visible in an lit area

I.2 Scenario 1: Highways Agency Traffic Officer Service



Figure 10-19: TOS scenario, luminance levels, additional lighting on

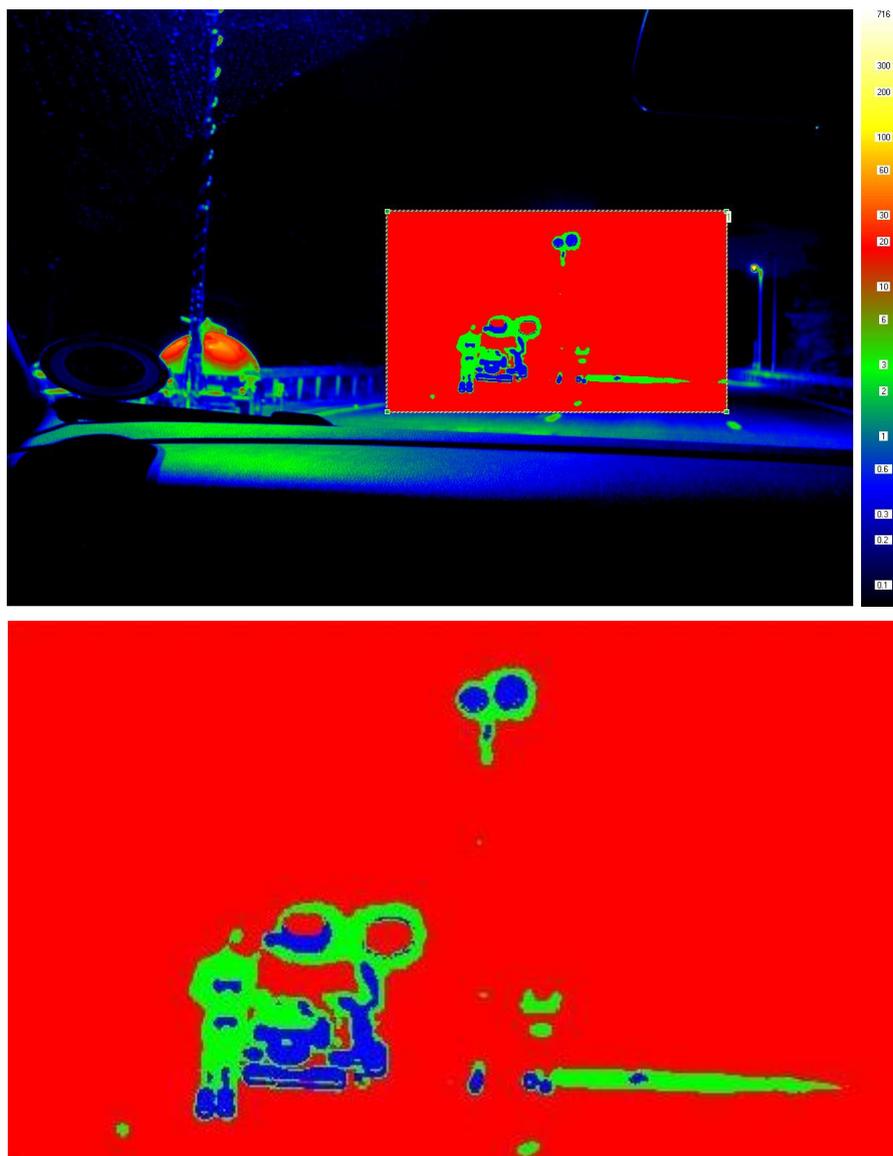


Figure 10-20: TOS scenario, luminance selected (red) area expanded to show detail

In the selected region:

- Red indicates a luminance less than 1 cd/m^2
- Green indicates a luminance greater than 1 cd/m^2 but less than 3 cd/m^2
- Blue indicates a luminance greater than 3 cd/m^2 (Note: this includes luminance values displayed 'red' in the previous image)

For the mannequin in the left of the region, by the rear door of the TOS vehicle:

- Most of the fluorescent clothing has a luminance of about 2 cd/m^2
- The reflective stripes on the upper body are about 3 or 4 cd/m^2
- The reflective stripes around the ankles are about 40 cd/m^2

I.3 Scenario 2: TTM/IPV Vehicle

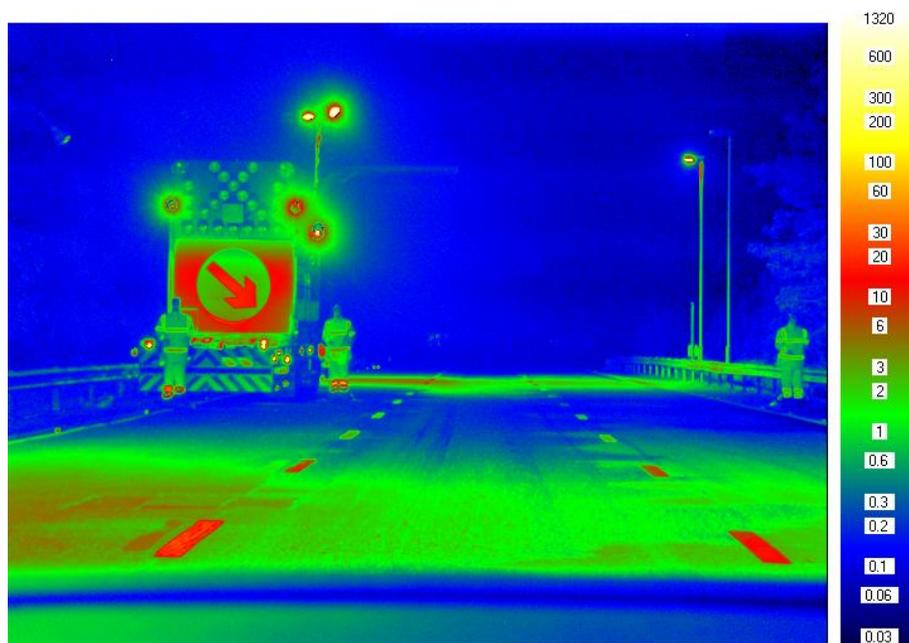


Figure 10-21: TTM/IPV scenario, luminance levels, additional lighting on

All three mannequins have similar luminance values, with the bodies of the mannequins on the extreme left and right of the image ranging from about 0.6–0.7 cd/m^2 . The centre mannequin is better illuminated by the car headlamps, with most of the PPE having slightly higher values between 1–1.5 cd/m^2 .

Table 10-1: Luminance values for reflective bands

Reflective Band	Left Mannequin	Centre Mannequin	Right Mannequin
Shoulder vertical	2.5	3.5	3
Upper chest horizontal	3	3.5	3.3
Waist horizontal	4.3	4.8	2.5
Ankles	50	112	4

While the ankles retro-reflectors can be very luminous, their area is very small and do not give much impression of a person as the reflectors act as point sources. The dipped headlight beam falls directly onto the mannequins' ankles so all of this area is lit up to some extent.

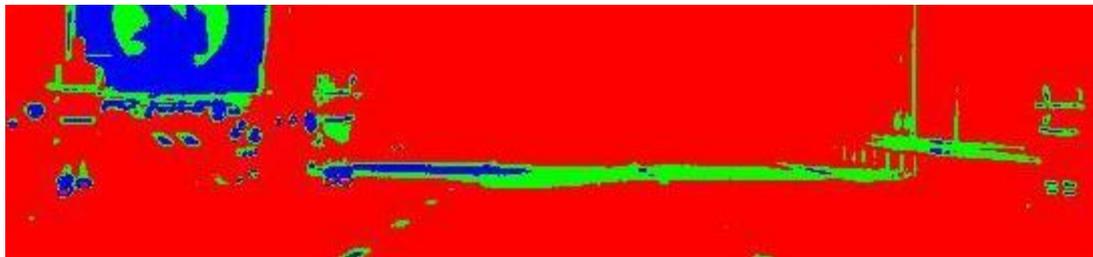
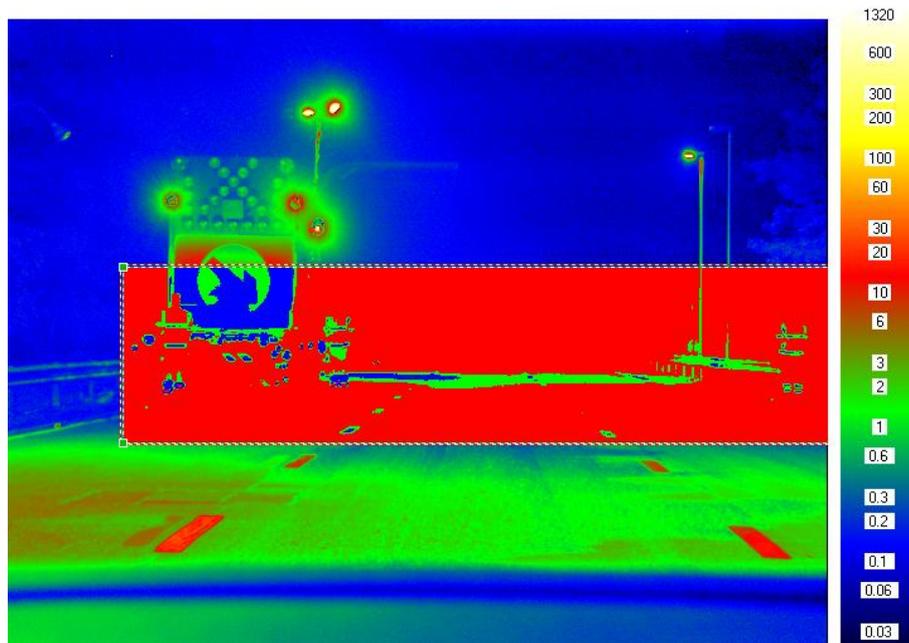


Figure 10-22: TTM/IPV scenario, luminance selected (red) area expanded to show detail

In the selected region:

- Red indicates a luminance less than 1 cd/m²
- Green indicates a luminance greater than 1 cd/m² but less than 3 cd/m²
- Blue indicates a luminance greater than 3 cd/m² (Note: this includes luminance values displayed 'red' in the previous image)

For the majority of the PPE, it is only the reflective bands which have a luminance greater than 1 cd/m².

I.4 Colour Board

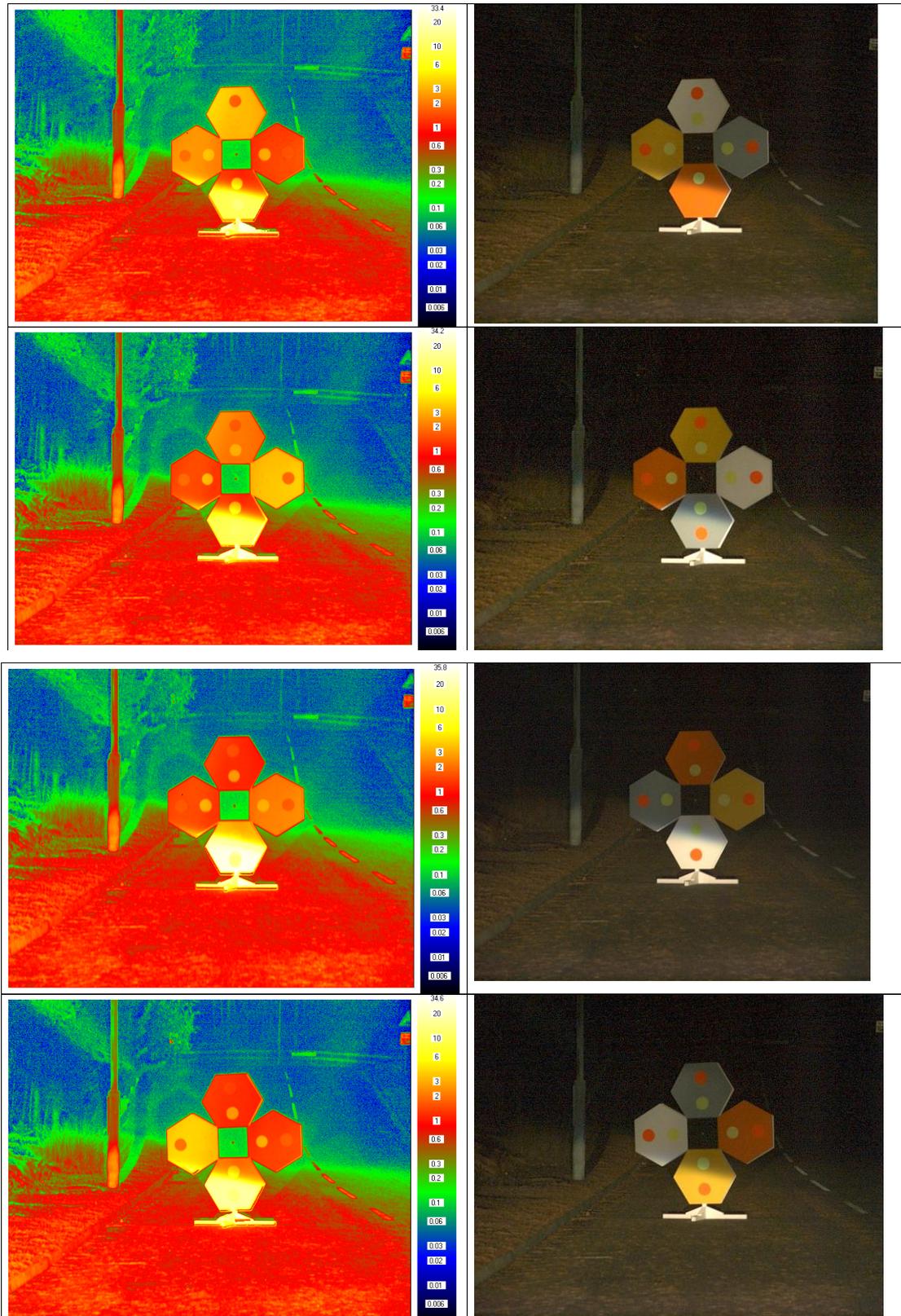


Figure 10-23: All orientations of colour board ('Beta' side) luminance image (left) and visible (right)

Appendix J Colour board trial researcher instructions

Researcher to explain second trial to test candidate:

Introduction

"In this task, you will be asked to make subjective judgements about how easy it is to see various targets on a board just down the road from us. I will ask you some questions once the full beam headlights of this car are on."

"There are no 'right or wrong' answers – we just want your opinions."

"Do you have any questions?"

Show participant recording sheet diagram, and state:

"You should say which target corresponds to the target that is easiest to see, in relation to the question I ask you."

"So for example, if I ask you which target from a, b, c and d is easiest to see, and you felt that target 'b' was easiest for you to see, then you would say "b""

RUN the trial:

Follow separate recording sheet.

Awkward Questions

Any awkward questions about what this bit of the trial is about:

"It is just so we can understand how people see different hazards at night – as I said there is no right or wrong answer, we just need your opinion"

Appendix K Colour board trial recording sheet

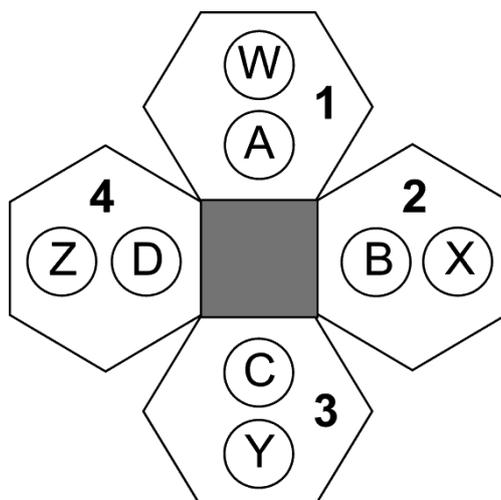


Figure 10-24: Trial 2 recording sheet diagram

Small road trial – Experimenter sheet – [date]

Date:

Participant number:

CHECK with small road system trial manager:

The **ALPHA / BRAVO** side of the board is facing the participant
YELLOW board is on the **TOP / RIGHT / BOTTOM / LEFT**

Question session using experimental car lights:

Question	Answer
1. Which is the easiest DOT to see overall?	
2. Which is the easiest board BACKGROUND to see overall?	
3. Which is the easiest DOT to see out of a, b, c and d?	
4. Which is the easiest DOT to see out of w, x, y and z?	
5. Which is the easiest DOT to see on board 1?	
6. Which is the easiest DOT to see on board 2?	
7. Which is the easiest DOT to see on board 3?	
8. Which is the easiest DOT to see on board 4?	

Appendix L Eyesight test instructions and materials

Participants were given two eyesight tests:

- A basic distance vision test viewing a vehicle number plate over a measured distance
- An Ishihara test for colour deficiency

L.1 Interviewer instructions

In this role you need to administer two simple eye tests. Note these are NOT diagnostic, they are merely an indication for the trial.

Distance test

Stand participant on metal strip in arch between SimSuite waiting area and corridor.

Open door to Sim hall, number plates on end wall.

Ask participant to read one of them ("Please read out the top number plate"), and note whether it is read correctly on the separate sheet.

Colour

Ask the participant to sit and place the book in a well-lit area.

Ask the participant to tell you what number they can read from each of the first 11 slides in the book (see separate response sheet).

Mark their response to each slide on the form.

If asked anything awkward:

"Is that OK?"

"Is my colour vision OK?"

Explain that these tests are not done under the same conditions as a full optician's eye test, and that they should contact an optician or doctor if they are concerned.

Handover to post-drive interview

L.2 Recording Sheet**Night-time visibility trials**

Participant no.	Date of test
------------------------	---------------------

Distance Vision

Number plate read correctly Y N

Colour deficiency test

Plate number	Response given	Correct answer	Correct response Y/N?
1		12	
2		8	
3		5	
4		29	
5		74	
6		7	
7		45	
8		2	
9		x	
10		16	
11		Traceable pattern	
		Total number of correct responses	

Note: 'x' shows that the plate cannot be read

Appendix M Interview materials

All participants were given a full interview after the trials.

M.1 Post-test Interview Script

Post-drive interview question and answer sheet

Date:

Participant number:

General driving

1. Do you drive regularly?	Yes/No
2. Do you drive regularly at night?	Yes/No
3. Do you drive regularly on motorways?	Yes/No
4. Do you drive regularly on motorways at night?	Yes/No

Eye-test history

5. How good would you describe your eyesight as being when using glasses or contact lenses if you use them?

6. Do you have any history of colour blindness?

Commentary drive

7. What kinds of things did you notice during the drive around the track?

8. When you drove past the final scene with the highways vehicle with flashing lights, can you remember what was at that scene?

9. Did you see any people at that scene?	Yes/No
--	--------

10. If you did see any people, can you remember how many you saw, and their location or locations? (*Show top-down view of scene and ask participant to mark on the scene where they saw any people, and if more than one, which they saw first*)

11. If you did see any people, would you say that you were actively looking for them while being driven towards the scene, or did you just happen to notice them?	Actively looking / Just happened to notice
---	---

12. If you were actively looking for people, what made you do this?

13. If you just happened to notice the any people, what made you notice them?

14. If you did see any people, can you remember the colour of any clothing they were wearing?

Everyday driving questions

15. When you see a vehicle stopped at the side of the road with flashing amber lights in your everyday driving, what do you associate this with?

a. For example, is there anything else you would expect to see?

16. When you see a vehicle stopped at the side of the road with flashing amber lights in your everyday driving, how often do you expect to see road workers (people) on foot? Give a number between 0 and 100, where 0 is 'never' and 100 is 'always'.

17. If you do expect to see road workers when you see a vehicle stopped at the side of the road with flashing amber lights in your everyday driving, where do you normally expect these road workers to be?

a. For example, would you expect them to be close to the vehicle, away from it, in the carriageway?

18. If you see a vehicle stopped at the side of the road with flashing amber lights in your everyday driving, do you change your driving behaviour?

a. What do you do and why?

19. If you see road workers in your everyday driving do you change your driving behaviour?

a. What do you do and why?

Give participant the following debrief and then allow them to leave to be paid by the people in reception.

This interview has been interested in a number of things, but in particular one thing we have been interested in the extent to which people associate flashing amber lights on vehicles with the presence of road workers on or around to the vehicle.

When you see a vehicle with flashing amber lights either on a hard shoulder or in a live (running) lane, you should expect there to be road workers working on or around the vehicle 100% of the time. Sometimes these workers will be close to or in front of the vehicle working on the side of the road, sometimes they may be in the carriageway laying cones for road works, or maybe even crossing the carriageway putting up signs or removing debris.

Thank you for taking part in the trial – I will now pass you over to the people in Reception to arrange your payment before you leave.

M.2 Scenario 2, Supplementary questions:

Amber beacons displayed on the scenario vehicle were distantly visible (approximately 200m) from the Test Track access route. Because of this, an additional question was asked at the end of the interview:

Did you notice any amber flashing lights while you were in the trials car before the track drive started?

If a participant answered 'Yes', a supplementary question was asked:

Did that influence your awareness of the scenario?

M.3 Scenario 'Top Down' plans

During question 10, participants were given a diagram to mark with the location(s) of any people they saw at the scenario scene, also identifying which one they saw first.

M.3.1 Scenario 1: Traffic Officer Service

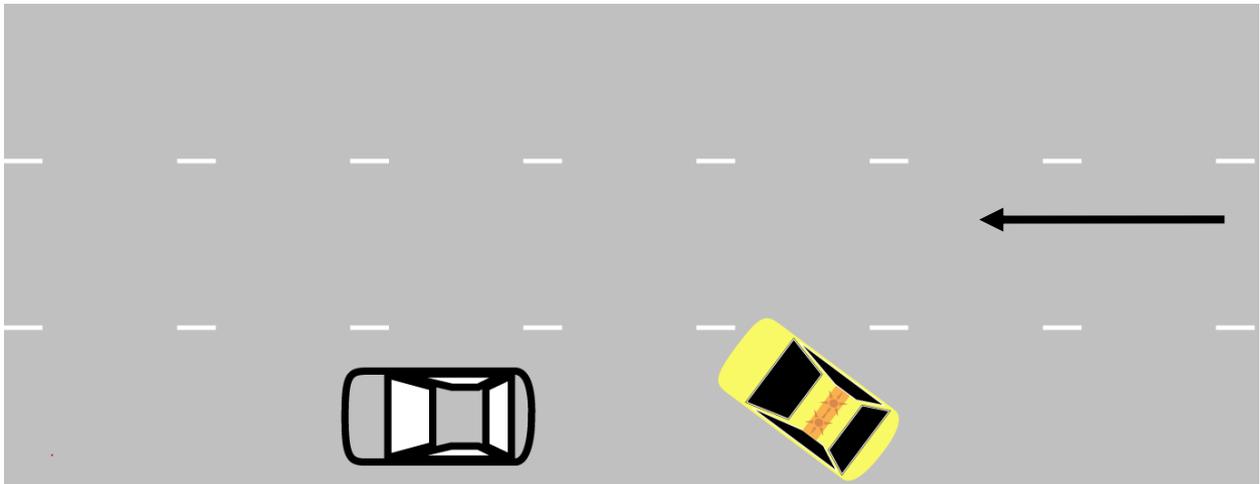
Plan view of final track scenario to assist with Question 10:

Date:

Participant number:

If you did see any people during the final track scenario (the one with the highways vehicle with flashing lights), can you mark their location or locations on the below plan view?

Remember that you drove past the scenario in the direction indicated by the arrow.



M.3.2 Scenario 2: Traffic Management Vehicle

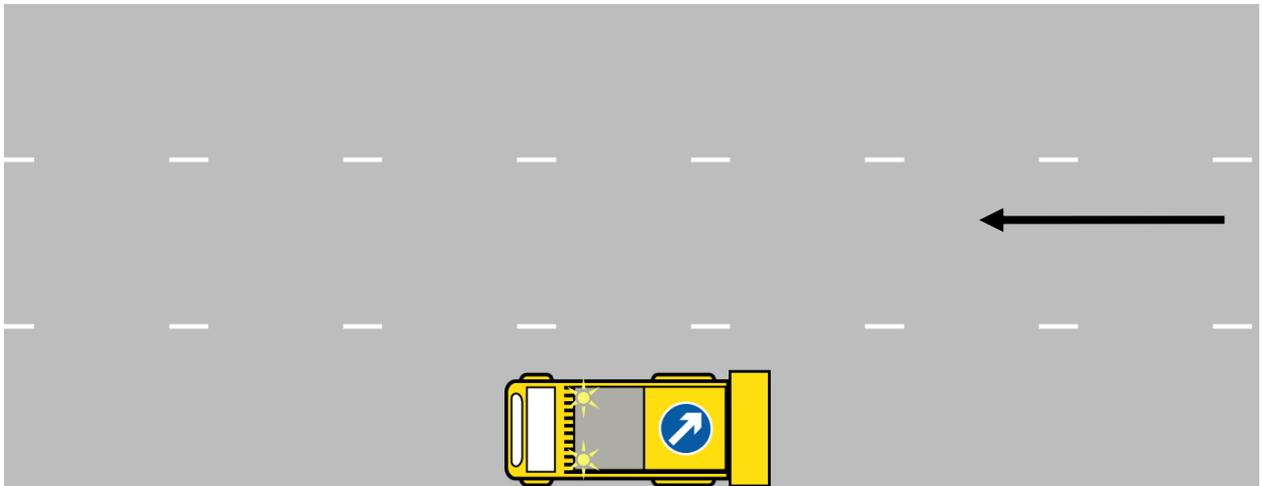
Plan view of final track scenario to assist with Question 10:

Date:

Participant number:

If you did see any people during the final track scenario (the one with the highways vehicle with flashing lights), can you mark their location or locations on the below plan view?

Remember that you drove past the scenario in the direction indicated by the arrow.



Appendix N 'Chapter 8', BS EN 471 and CIE 1931

N.1 Road worker high visibility clothing and vehicle markings

The visibility of clothing worn by road workers is specified in Traffic Signs Manual 2009 Chapter 8 Traffic Safety Measures and Signs for Road Works and Temporary Situations (TSO 2009), which specifies clothing manufactured according to BS EN 471. Part of this specification covers the range of colours acceptable to meet the standard; these colours are specified by reference to CIE 1931.

Chapter 8 also specifies the high visibility markings to be displayed by road works vehicles.

N.2 'Chapter 8'

'Chapter 8' is the acknowledged 'shorthand' for the Traffic Signs Manual 2009 Chapter 8 Traffic Safety Measures and Signs for Road Works and Temporary Situations, which contains what may be considered as representing what is reasonably practicable for the enforcement of the Health and Safety at Work etc. Act 1974, the Health and Safety at Work (NI) Order 1978, and associated regulations.

The following excerpts cover the scope of the document, and detail its application to vehicle and road worker conspicuity:

"Part 2: Operations, provides guidance for those responsible for planning, managing, and participating in operations to implement, maintain and remove temporary traffic management arrangements. It contains advice relating to good working practice spanning all aspects of temporary traffic management operations from broad management issues to issues involving the activities of individual operatives."

"Chapter 8 is intended to provide a standard of good practice for the signing and marking of obstructions as well as for the temporary traffic control necessitated by such obstructions of the highway. The standard described is a minimum, which should always be achieved."

"This Chapter sets out a code of practice to enable the legal requirements to be met in a wide variety of circumstances, although it has no statutory force, except in Northern Ireland where an authorised officer for the Department may deem it to have such force. (In Northern Ireland, Article 31 (or equivalent) is the legal status that deems Chapter 8 to be a legal document for certain roads only and only for the signs and devices used.) All authorities, bodies and organisations responsible for all types of roads to which the public have access are strongly recommended to make compliance with the requirements of Chapter 8 a condition of contract in the case of works carried out on their behalf."

"05 General Vehicle Issues

"05.2 CONSPICUITY

"05.2.1 Any vehicle stopping on the highway for works purposes or inspections should be of a conspicuous colour (e.g. yellow or white). A non-reflective yellow colour, No. 355 (lemon) to Table 1 of BS 381C: 1996 "Specification for colours for identification, coding and special purposes" is recommended.

"05.2.2 Subject to the specific requirements of the following sections, any works vehicles that are used to protect the workforce or form part of the signing of the works should be of conspicuous colour and appropriate marking. This is particularly important

for that part of the vehicle visible to drivers and prescribed as part of any sign mounted on the vehicle.

"05.2.3 In addition, on high-speed roads, all vehicles stopping on the highway for works purposes or inspections shall be equipped with high visibility rear markings. High visibility rear markings should comprise either:

a) signing to diagram 7403, or

b) the alternative light arrow sign in accordance with Section O10.8, or

c) chevron markings comprising alternate strips of fluorescent orange-red retroreflective material and fluorescent yellow non-retroreflective material, of not less than 150mm width each, inclined at 45-60° to the horizontal and pointing upwards, or

d) a solid block of fluorescent orange-red retroreflective material."

"06.3 PERSONAL PROTECTIVE EQUIPMENT (PPE)

"06.3.1 Whenever possible exposure to hazards should be eliminated or otherwise minimised at source by careful selection of the method of working, plant and material being used, rather than by the issue of personal protective clothing and equipment (PPE) e.g. by minimising noise at source rather than providing hearing protection. The use of PPE shall not be considered as an alternative to efforts to eliminate or reduce risks. If hazards cannot be eliminated, items of PPE may assist in controlling the residual risk.

"06.3.2 The workforce and site supervisory staff should wear high visibility warning clothing at all times when on site. Clothing shall comply with BS EN 471 Table 1, Class 2 or 3 (Class 3 on motorways or other high speed roads) and shall comply with the requirements of paragraph 4.2.3(b) of the Standard. The colour of the clothing shall normally be fluorescent yellow or fluorescent orange-red complying with Table 2 of the Standard. The retroreflective material shall be to Class 2 as defined in Table 5 of the Standard. In addition, on motorways and other high-speed roads, high visibility jackets or coveralls shall have full length sleeves meeting the requirement of paragraph 4.2.4 of BS EN 471. This requirement may be varied to three-quarter-length sleeves where a risk assessment shows full length sleeves would present increased risk due to the activity being undertaken. Staff should also wear high visibility trousers complying with Class 1 of BS EN 471 where the carrying of large items of equipment or other activities may at any time obscure the visibility of the high visibility jacket or vest."

N.3 BS EN471

BS EN471 is the European standard which specifies test methods and requirements for high-visibility warning clothing for professional use. The following excerpts cover design requirements:

"This European Standard specifies requirements for protective clothing capable of signalling the user's presence visually, intended to provide conspicuity of the user in hazardous situations under any light conditions by day and under illumination by vehicle headlights in the dark.

"Performance requirements are included for colour and retro-reflection as well as for the minimum areas and for the disposition of the materials in protective clothing.

"However users should consider the prevailing ambient background in which protection is required and select the colour that provides the preferred contrast.

"This European Standard provides a solution that enables the major issues to be resolved. The performance of the conspicuous materials to be used in "high visibility clothing" is specified together with minimum areas and placement of the materials.

"Conspicuity is enhanced by high contrast between the clothing and the ambient background against which it is seen; and by larger areas of the conspicuous materials specified.

"Three areas of background and combined performance material colours are defined in an appropriate manner for clothing material, all of which will confer conspicuity against most backgrounds found in urban and rural situations in daylight. However users should consider the prevailing ambient background in which protection is required and select the colour that provides the preferred contrast.

"Two levels of separate performance retroreflective materials are included. Higher levels of retroreflection provide greater contrast and visibility of warning clothing when seen in headlights during darkness. When greater conspicuity is required the higher level of retroreflecting material should be used.

"Design requirements illustrating the disposition of retroreflective materials are included within the standard. The ergonomics of the wearer should be considered when selecting the most appropriate configuration of retroreflective materials within the garment. Three classes of warning clothing are specified in terms of the minimum areas of the materials to be incorporated. Whilst the area comprising clothing is obviously dictated by the type of clothing and also the size of the wearer, it should be noted that class 3 clothing offers greater conspicuity against most urban and rural backgrounds than class 2 garments which in turn are significantly superior to class 1 clothing."

N.4 CIE1931

Chapter 8 specifies that:

"06.3.2 The workforce and site supervisory staff should wear high visibility warning clothing at all times when on site. Clothing shall comply with BS EN 471 Table 1, Class 2 or 3 (Class 3 on motorways or other high speed roads) and shall comply with the requirements of paragraph 4.2.3(b) of the Standard. The colour of the clothing shall normally be fluorescent yellow or fluorescent orange-red complying with Table 2 of the Standard."

BS EN471 specifies chromaticity for those colours described:

"5.1 Colour performance requirements of new materials

5.1.1 Background material

The chromaticity shall lie within one of the areas defined in Table 2 and the luminance factor shall exceed the corresponding minimum in Table 2."

For comparison, the UK rail industry mandate the use of high visibility clothing which complies with BS EN471 Class 2 in respect if the minimum area of visible materials. However, the background colour is defined more tightly as 'fluorescent orange', with a smaller chromacity range acceptable.

Table 10-2: From BS EN471: Colour requirements for background and combined performance material

Colour	Chromaticity coordinates		Minimum luminance factor β_{min}
	x	y	
Fluorescent yellow	0,387	0,610	0,70
	0,356	0,494	
	0,398	0,452	
	0,460	0,540	
Fluorescent orange-red	0,610	0,390	0,40
	0,535	0,375	
	0,570	0,340	
	0,655	0,345	
Fluorescent red	0,655	0,345	0,25
	0,570	0,340	
	0,595	0,315	
	0,690	0,310	

Table 10-3: From GO/RT 3279: Colour requirements for background material ("rail orange")

Colour	Chromaticity coordinates		Minimum luminance factor β_{min}
	x	y	
Fluorescent orange	0,610	0,390	0,4
	0,640	0,360	
	0,585	0,355	
	0,560	0,380	
Target colour	0,588	0,371	

The chromaticity coordinates specified relate to the CIE 1931 colour space diagram, with each set of four coordinates defining an area within the graph shown below:

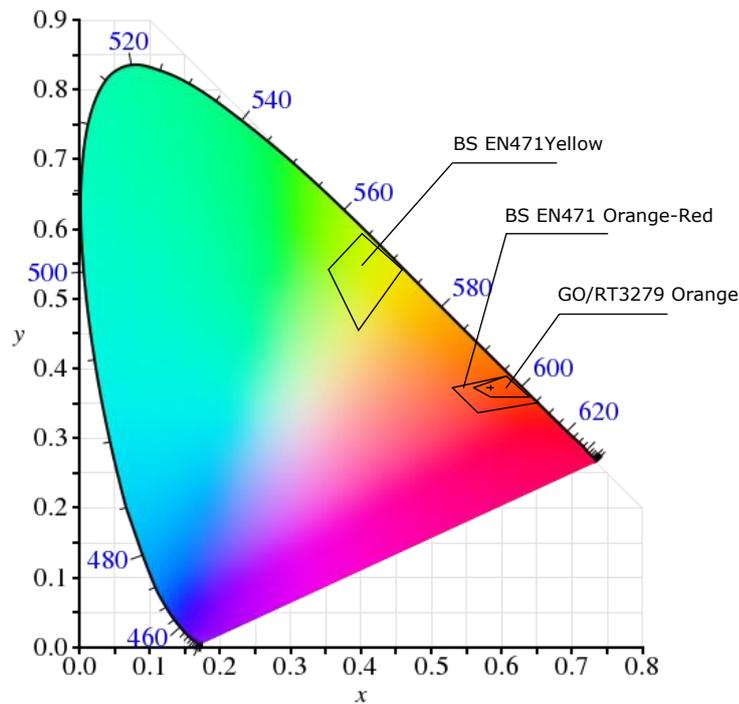


Figure 10-25: CIE 1931 Colour Space, with approximate locations of chromaticity tolerance co-ordinates for BS EN471 yellow, BS EN471 orange, GO/RT3279 orange, and (cross) target chromaticity of GO/RT 3279

N.5 Colour fastness

BS EN471 specifies performance requirements, including for colour fastness under the following:

- After xenon test.
- Of background material and non-fluorescent material after test exposure.
- To rubbing.
- To perspiration.
- When laundered, dry cleaned, hypochlorite bleached and hot pressed.

Similarly, clothing manufacturers specify appropriate cleaning methods for their products, typically including recommendations on the maximum number of wash cycles after which the clothing should be replaced.

Also, colour performance will be adversely affected by any soiling during use.

Appendix O Video cameras & voice recorders

O.1 Video Cameras

Both on-track trials were recorded for later review and analysis. A video camera was rigidly-mounted within the trials cars, set up to obtain a view between the driver and participant, similar to that available to them.

The cameras used were Sony Handycam HDR-UX7, recording onto DVD.

O.2 Voice Recorders

All participant interviews were digitally recorded, using Olympus DS-4000 Digital Voice Recorders.

Glossary of terms and abbreviations

Fend Off Vehicle parked at an angle of approximately 10° from straight ahead, with the front of the vehicle towards the 'live' (traffic) lane

IPV Impact Protection Vehicle

PPE Personal Protective Equipment

TOS Traffic Officer Service

TTM Temporary Traffic Management