PPAD 9/33/39
Quality and field of vision – A review of the needs of drivers and riders

Final report

Prepared for:

The Department for Transport, Local Governments and the Regions

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Executive summary

Driver/rider vision has been identified as a significant determinant to road safety. Its relationship to windscreen/visor tinting, installed light transmission, haze, abrasion, damage/repair and reflection forms the basis of this research programme.

A review of the research to date indicated that there was little, if any, accident data available to quantify the relative contribution of these aspects to road accidents; a finding supported by our own research into accident data in this area. However studies already undertaken suggest that tinting is only problematic for low contrast objects under conditions of low ambient lighting. In addition there is some indication that abrasion and haze (the build up of dirt on the screen interior also referred to as contamination) may be more problematic than tinting.

A review of relevant Directives, Regulations and Standards was undertaken along with a review of current expert opinions. Specific surveys of driver and rider opinions confirmed and prioritised the aspects identified above as problematic to driving/riding. A further survey of visor usage indicated that visors with a luminous transmission <50% (the legal daytime minimum) were available for use on the road and that visors with a luminous transmission <80% were frequently used on the road in low ambient lighting conditions. Misuse of visors is therefore a facet of motorcycle riding which needs to be considered when determining limits for luminous transmission levels.

Based on the above research an extensive experimental test programme was developed to investigate key areas in depth. The experimental work was based on the detection of roadway hazards, such as the presence of pedestrians, under various ambient lighting conditions. This work indicated that reduced luminous transmission did not improve rider/driver safety since target objects were detected equally well under all luminous transmission levels in bright daylight i.e. there was no significant difference in the detection rates across the various levels of luminous transmission. Previous research and investigations within this study suggest that comfort may be a factor in the use of tinted materials.

Recommendations based on the test programme and on vehicle surveys of windscreen abrasion and contamination can be made as follows:

- The experimental work confirms that materials with a luminous transmission of 33.4% perform as well as those at 74.5% in terms of detecting objects in the roadway and so this defines an acceptable lower limit. Further analysis extrapolating from these results suggests that this lower limit may be reduced to around 27% but this requires verification through experimental work including field trials and older people and spectacle wearers for whom detection performance is reduced by low luminous transmission levels. Since this does not provide the same extent of tint as that defined in BS EN 1836:1997 for dark tinted sunglasses (8-18%) and very dark tinted sunglasses (3-8%) it is suggested that two-stage visors may provide some compromise. Peaks, providing shade, are also of benefit.
- A minimum transmission level of 12.5% for combinations of materials (e.g. sunglasses & screens) was defined by Morris et al. (1991) for avoiding a reduction in visual acuity, spot detection and contrast sensitivity.
- Based on the average from our sample vehicles, windscreens should be considered for replacement at 110,000 miles after installation to determine if the detrimental effects of abrasion warrant replacement. Much is dependent upon extent of use, type of use, storage, geographical location, etc.
- In addition to keeping the outside of the windscreen clean, the interior surface should also be cleaned. Based on our sample windscreen interiors should be cleaned at least every 859 miles or 19 days.

In terms of future progress, it is recommended that the following aspects are prioritised for further development:

- Verify the lower level of luminous transmission which at which detection performance does not significantly differ from the current minimum luminous transmission for windscreens of 75%.
- Daytime testing to quantify the glare reducing benefits of various levels of tinting.

- Increase the sample number and the number of regions surveyed for windscreen abrasion and contamination to ensure nation-wide representation.
- The causes, effects on detection and means of minimising the disbenefits of reflections should be investigated, since this was identified as primary source of visual problems in the driver survey.
- Visor fogging was identified as an area of concern in the rider survey and in a survey undertaken by the Health and Safety Executive. A method which could be used to measure the amount of time it took for the clarity of a viewed image to be reduced to 50% and 75% of its original value was devised by Vaughan et al (undated) in response to the HSE survey. Further investigation should be made to determine if this work and ICE's work on veiling glare luminance could form the basis of a future test for motorcycle visors for reduced clarity due to fogging. Fogging was also identified as an area for further investigation with respect to cars since one third of the drivers whom ICE surveyed indicated that they used the car's fan to clear the screen *while driving*. The acceptable minimum levels to which the screen must be demisted in the shortest possible time, and the areas of the windscreen to which this should be applied, should be further investigated.

Means to improve the quality of accident data should be investigated. Initial investigations could be made as part of the On-The-Spot study currently being undertaken by the Department

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1.0 Introduction

It is the responsibility of the Department of the Environment, Transport and the Regions (DETR) to promote safe use of the UK road network. Driver vision has been identified as major determinant to this and factors which impede it require further investigation.

This project is specifically concerned with the effect on driver / rider vision of: windscreen and visor tinting, installed light transmission, haze, abrasion, damage/repair and reflections. Refer to Appendix 1 for a full outline of the project requirements.

The research activities undertaken as part of this project and the extensive test programme derived from them are documented in this report.

2.0 Research review

2.1 Rider vision

Road accident statistics generally tend to show that the rate of motorcycles involved in road accidents is higher than cars. For example, an accident study in Germany found that of 10000 licensed vehicles in 1983, the number of fatal accidents involving cars was 25, while for motorbikes, it was 62 (Timmerman, 1985). There could be a number of possible contributing factors to the higher level of motorcycle fatalities. The motorcyclist's failure to see the oncoming hazard could be one such factor. This may be a result of the riders own negligent behaviour (carrying out other tasks which takes their attention away from the road ahead) or due to equipment failure (reduced vision through a visor). Vision through a visor can become reduced through dirt and also when cleaning the visor, abrasions may occur. A visor fitted poorly to the helmet may also lead to abrasions (Waters, 1982). In addition, vision can be reduced by using a tinted visor.

2.1.1 The Function of Visors and Goggles

The main function of visors on crash helmets and goggles is to help with rider vision by preventing the wind, dust particles, dirt and other foreign objects getting into riders' eyes. However, visors may not assist riders' vision when faced with high levels of glare. Glare has been defined as "the dazzling sensation of a relatively bright light which produces unpleasantness or discomfort, or which interferes with optimum vision"(Phillips and Rutstein, 1965). Road users will experience two main types of glare on the road. Firstly, glare could occur at night when driving towards oncoming vehicle headlights. It has been shown by a survey carried by the former Road Research Laboratory (now the Transport Research Laboratory) that 15% of oncoming vehicles dazzled drivers (Phillips and Rutstein, 1965). Secondly, daytime glare experienced on sunny days, particularly when the sun is low shortly before dusk and when the sun is shining on wet roads, can be a particular problem to riders of motorcycles.

At present, motorcyclists are required to use helmet-mounted visors or goggles which conform with BS4110 (1979: Specifications for Eye Protectors for Vehicle Users) allowing transmittance levels of no less than 50% during the day, to allow for some daylight glare protection, and no less than 80% at night.

2.1.2 Abrasions

A study by Timmerman (1985) looked at how motorcycle helmet visors can contribute to a loss of clarity of vision, particularly after receiving abrasive damage over a high level of usage. Of the 400 visors in use which were tested, the average scattered light component was calculated at 14.4% (i.e. on average, 14.4% of the visors' surface had scattered light), with moped riders as a group having the worst average scattered light level at 21%. It was also found that moped riders and the less experienced motorcycle riders were generally those who used poor visors in terms of the level of damage and from studying accident data, young inexperienced riders were also those who tended to be the ones who were involved in the most accidents involving injuries. It was therefore concluded that damaged or abraded visors increase the risk of accidents to motorcyclists and that to reduce the likelihood of abraded visors being used on the road, better scratch-resistant materials should be used and a greater awareness of the risks of badly abraded visors should be enforced at rider training level.

2.1.3 The use of tinted visors in daylight

Helmet sun visors used by U.S. Navy jet pilots were assessed in terms of their visual acuity in a study by Morris et al. (1991). This report consisted of two studies.

Firstly, the visual acuity of helmeted pilots was tested under four daytime conditions, these being high and low contrast stimuli and low contrast under glare, with and without visors of 12% transmission. The results revealed that the threshold of visual acuity was worst when with low contrast stimuli under glare when using a visor and was significantly worse than the reduction in acuity under glare with no visors. This suggests that visors of 12% transmission may reduce exposure to glare but also considerably reduce the visual acuity threshold.

The second study investigated the effects of five visor's transmittance on contrast acuity, spot detection and sensitivity. The transmittances investigated were 100% (i.e. no visor), 50%, 25%, 12.5% and 6.3%. In terms of spot detection, the spot was required to be significantly larger to be seen with 6.3% transmission than with all other filters, while acuity was found to be worse with the same transmission compared with having no filter at all, but no differences were found with other filter transmissions. In terms of contrast sensitivity, filter density was not a significant factor. It was concluded that filter density can be varied over a wide range before significantly affecting acuity, spot detection or contrast sensitivity (down to 12.5% transmission) and suggest that at least 500cd/m^2 should reach the eye when wearing visors or sunglasses. This appears to be in conflict with the currently used BSEN1836:1997, concerning sunglasses which provides for a minimum luminous transmission value of 8% for driving. However, BSEN1938 (motorcycle goggles) appears to have taken this into account by limiting luminous transmittance to a minimum of 18%, the difference probably being due to the categorisation of light transmittance values in BSEN1836.

2.1.4 The use of tinted visors at night

Cooper (1983) undertook research to investigate the effects of tints on distance at which objects on unlit roads can be seen at night. Practical tests were carried out by measuring an observer's seeing distance of an object positioned just beyond a glare source (dipped headlights). It was found that seeing distance was reduced by about 6% (3 metres) when a tinted visor of 41% transmission was used instead of a visor with 90% transmission. A theoretical method of measuring seeing distances for different degrees of transmission, with and without glare, was also undertaken. The results supported the findings of the practical tests, as a predicted reduction in seeing distance of 3.4 metres was calculated.

Other evidence to support a prohibition of tinting at night was outlined by Wolf et al. (1960, in McLean et al, 1979), who suggested that tinted glass impedes dark adaptation, visual acuity and depth perception.

The undesirability of the use of tinted visors at night was also commented upon by Gilkes (in Waters, 1982) who found no evidence that the use of tints offer any clear advantage and so to avoid any misuse should not be permitted at all.

In documents forwarded by DETR on “Speed Related Severity To Motorcyclists” and “Reduction in Seeing Distance Caused By Tinted Visors And Its Effect On Motorcycle Impact Velocity”, it was reported that reduced visor transmittance leads to reduced seeing distances, therefore impact velocities increase, which in turn increases the chance of a more serious injury occurring. As a result, it was recommended that visor tinting should be prohibited.

An article in the journal “Motor Cycle Rider” (1997) states the case for reducing the allowable daytime minimum transmission of tinted visors from the current level of 50% as specified in BS4110. The motorcycle eye protector BSI sub-committee proposed amendments which included better impact resistance, improved abrasion testing and the use of heavier tints (with 18% transmission) to protect from sun glare. It is stated that to provide riders with effective glare protection, a transmission level of 25% would be necessary. As it is stated in this article that contemporary research shows that “scratching is the primary cause of accidents” but “heavily tinted visors fail to play a major part”, reducing the minimum transmission tinted visors for use during daylight should not increase accident risks, particularly if interchangeable tinted/clear visor pairs are used which are safer and easier to remove than wearing sunglasses behind a visor.

In 1997, when submitting evidence to the BSI sub-committee, DETR explained why the current minimum transmission for tinted visors should not be reduced from 50% to 18%. A reduction was said not to be appropriate for visors as they are not easy to change or remove when light conditions suddenly deteriorate, which could encourage misuse.

2.1.5 Tinting vs Abrasions

As part of an in-depth accident study carried out by the University of Adelaide Road Accident Research Unit (McLean et al, 1979), trends in motorcycle accidents, including evaluating the effectiveness of existing safety measures, were investigated. Accidents involving riders who were wearing visors were examined to determine the extent to which the visors contributed to the accident. Sixteen of the sixty-nine riders involved in the study had clear visors fitted to helmets. The nine visors which were scratched or dirty were not thought to have affected the riders pre-accident performance. Of the four occasions where clean tinted visors (level not specified) had been worn, it was suggested that one visor may have contributed to the accident, as the rider had failed to see a parked car, but this was one of many factors which could have contributed to the accident.

Another case mentioned in this study involved a rider who was wearing glasses with photosensitive lenses in addition to a scratched tinted visor (level not specified). It was possible that, although the rider was looking downwards to locate a noise, the visor contributed to the accident because the rider again failed to see a parked car. Both this and the previous accident were similar in that they both occurred under night conditions. At the time of publication, the use of tinted visors (less than 85% transmission) was completely prohibited in Australia (AS1609)(Wigan, 1979) and this study appears to support this at least for night conditions.

An individual case discussed in Waters (1982) involved a rider who was wearing a tinted and abraded visor (34% transmission) at night at the time of driving in to the back of a parked truck (Hope Ide et al. 1981). Visual acuity tests were carried out on the visor to determine the extent to which it would have contributed to the accident. This revealed that the visor did greatly impair vision and that it was the tinting which was more important than abrasion in reducing the vision.

An accident study carried out by Pedder and Hagues (1981), also reported in Waters, found that, of the 117 helmets recovered from fatal accidents, 53 had visors, of which 6 were tinted (level not specified), and one was accompanied with goggles. Nearly half of all the visors were considered abraded enough to impair the rider’s vision and four were known to have contributed to causing the accident. Of the tinted visors, one was thought to have contributed to the accident, but this visor was also badly abraded, so it could not be said which was the greater contributory factor to the accident. Therefore, it was concluded that abrasions could be a factor in 8% of motorcycle accidents, but no conclusions could be made about tinting because the sample of tinted visors was very small and all tinted visors were abraded to some extent.

Another study by Pedder and Hague (in Waters, 1982) tested visual acuity on various tinted and abraded visors, again at night. The effect of moderate tinting did not move the visual acuity along the visual acuity scale by more than one point and serious reductions in acuity were not found until there was marked scratching of the visor. It was therefore concluded that “the use of moderately tinted visors down to 50% have not shown to be a serious hazard and, if daytime use continues to be allowed, consequences of occasional inadvertent or deliberate abuse of them don’t appear to be likely to be serious”. In other words, reductions from 80 to 50% transmission would not cause a serious hazard, but would below 50%.

2.1.6 Coloured Lenses

Up to now, the reviewed literature has only reported results concerning visors of neutral density or grey. However, a study into yellow coloured lenses for the purpose of night driving was undertaken by Phillips and Rutstein (1965). They reported on research which found that wearing yellow glasses at night improves subjective discomfort, glare and fatigue, but that visual acuity decreased or was at least no better when wearing glasses tinted with colour. The study by Phillips and Rutstein themselves investigated into how tinted spectacles and contact lenses affect recovery times after experiencing glare from an oncoming vehicle. The results found that although the majority of participants expressed an increase in comfort, their visual performance was worse, i.e. glare recovery times were increased significantly, when wearing tinted spectacles and contact lenses.

2.1.7 Visors - Safe Practice

The Department of Transport (1981) have endeavoured to ensure riders do not use tints at night by outlining in a Proposed Manual on motorcycling the uses of visors and goggles. Their advice to riders is to not use when scratched, pull over and clean visors if dirty, not to use tints at night, not to spray tinting material on and to wear corrective lenses if necessary. The use of clean visors is also outlined in a training leaflet published by the Royal Society for the Prevention of Accidents (RoSPA, 1991) aimed at new motorcyclists and the 1978 version of the Highway Code advises the rider “do not use tinted optical equipment of any kind at night or in conditions of poor visibility” (in Waters, 1982).

Wigan (1979) undertook a review of the standards in use at the time in Australia and other parts of the world for automotive eye protection including visors and goggles. In terms of visors, most standards tend to agree on a minimum transmittance level of around 85% for a clear visor, including AS1609, German standard DIN 58218 and US Voluntary Standard VESC-8 (Vehicle Equipment Safety Commission). In addition, VESC-8 also states that a visor with less than 85% transmittance should be considered tinted and should not be used at night. This paper concludes that more research is needed into the extent to which tinted and abraded visors contribute to the cause of accidents to make specifications more clear cut and until this is done, the quickly replaceable tinted and clear visor pair appears to be the most effective way to overcome conflicts in requirements.

2.1.8 Visors - Subjective Opinions

A number of studies have carried out surveys involving visor users and their opinions on the use of visors. U.S. Navy jet pilots involved in the study carried out by Morris et al.(1991) were asked about visors and sunglasses. It was found that there was much variation in the uses of sunglasses and the types worn. It was suggested by some pilots that a variety of visors with a range of optical densities should be available rather than the single density in use at the time, so they could use the visor which suited them best.

Wigan (1979) reported that users of motorcycle visors prefer clean, unscratched visors to scratched clear visors for use at night and to protect from glare when wearing a clear visor, it was advised by optometrists to wear sunglasses in the visor. However, there were many disadvantages to this (i.e. potentially increased scatter, physical danger in an accident, difficulty to remove when riding). It was also suggested that users will use alternatives to clear visors if they are unable to wear tinted visors to protect themselves from glare, including no face protection at all and sunglasses with unknown impact protection.

2.1.9 Other Aspects which may affect visual acuity through visors

As well as tinting and abrasions, there was also a limited amount of discussion in the literature concerning other aspects which may affect the quality and field of vision through motorcycle visors, such as fogging and visor rake angle. A report by Vaughan et al. (undated) looked into developing a test method to assess the fogging of complete eye protectors. This study was carried out after it was found from a survey carried out by the Health and Safety Executive that fogging was the main reason why eye protectors were not being used when needed. A method was devised which could be used to measure the amount of time it took for the clarity of a viewed image (in terms of frequency) to be reduced to 50% and 75% of it's original value. It was suggested that this could be of use in the future to test motorcycle visors for reduced clarity in terms of fogging.

It was commented by Wigan (1979) that motorcycle visors are very prone to fogging, and combined with abrasions and dirt, can be more important to the user in terms of reducing vision than tinting. The severity of the rake of a helmet visor, which can often be up to 30^{o}, could also have a negative effect on visual acuity.

Hayward and Marsh (1988) tested how tinted visors with transmission 33.6% affected a riders area of visual field. The results revealed that the area of visual field was no different, with or without the tinted visor. However, this was mainly due to the visual field already being reduced by the helmet thereby possibly making any effect the tint may have had on target detection.

2.1.10 Conclusions to rider vision

To conclude, the literature tended to suggest that there was difficulty, when looking at accident data, in determining the level of contribution tinting and abrasions have on the cause of accidents, as it is rarely the case that a tinted visor involved in an accident will not be abraded as well. It is also often difficult to say whether either were the main cause of an accident.

From looking at the experimental studies, it appears that abraded visors reduced visual acuity more than tinted visors and at a quicker rate. Most studies tend to agree that tinted visors are acceptable at day, sometimes at lower transmissions than the currently accepted 50%, but should be strictly prohibited at night. Interchangeable tinted/clear visor pairs appear to be a more acceptable and efficient way of getting the most out of tinted visors for day and clear visors for night (Wigan, 1979) and helps to reduce visor misuse. This is opposed to the method of wearing sunglasses under clear visors, which some riders have been reported to do. The work of Morris et al. (1991) suggests an acceptable transmission level of 12.5% for combinations of materials (e.g. sunglasses & screens) to avoid reducing visual acuity, spot detection and contrast sensitivity. Therefore, the minimum for testing could be set at 18% (filter category 2 as described in BSEN1836 - see table 6 in section 3).

Very little research on the fogging of visors was found to be available to evaluate the extent to which it could affect the visual acuity of motorcycle riders and understand the extent to which it could be a problem. However, methods have been developed to determine reduced clarity due to fogging (Vaughan et al, undated).

2.2 Drivers vision

The project scope, as defined in section 1.0 of this report, included an investigation of those factors which affect driver vision. The literature reviewed has indicated that the factors which affect the quality of vision through the windscreen have undergone investigation in the past twenty years as discussed below.

2.2.1 Tinting

There are two opposed bodies of thinking regarding the tinting of vehicle glazing. One body, who would like to see transmission levels lowered, believe that there is a net benefit to the road user population in doing this. The other body hold the opinion that the risk to safety is not outweighed by the benefits tinting provides.

Tinting and accidents

Benefits

A common concern expressed by the anti-tinting body is that increased tinting will lead to increased levels of accidents. However, studies by Gittelsohn 1973 and Hills 1976 show this not to be the case. In Hills' work a statistical analysis of more than 6000 accidents indicated that vehicles with tinted windscreens:

- Were not over-represented in day and night-time accidents,

- Did not present an increased risk when used by older drivers at night-time compared to during the daytime (Hills 1976).

However other authors have suggested that there were insufficient statistical controls on this data to be confident that accidents are not increased.

Disbenefits

Little research concerning the affect of tinting on road accidents was found. McFarland et al (in Clark 1993) showed that the night-time accident rate reduces as illumination increases. He argued that since the converse must be true, by increasing the levels of tinting (no levels specified), this is likely to increase the night-time accident rate. It was estimated that the ambient lighting from street lighting, signals, etc would need to be increased by 15% to compensate for the effects of tinting. Similar work by Wolf at al (in Proffitt 1996) found that for a given level of dark adaptation, the threshold for detecting light increases when viewing through tinted glass by an amount corresponding to the reduced transmittance value i.e. it takes 30% more light to see a target through 70% transmittance glass

In 1991 in Australia, the tinting of the Primary Vision Area (PVA) of the windscreen was decreased from 85% to 75% following pressure from the motor trade. The PVA is defined as the "area of the windshield through which the driver sees the road ahead and its traffic". Those not in favour of tinting estimated a 2% long-term increase in the night-time road accident rate at an additional cost to Australian road users of $40million per annum. They concluded that the daytime benefits do not compensate for this (Clark 1993).

Clark also stated that research which states no increase in accidents due to tinting is frequently subject to experimental bias, poor statistics, etc, and therefore must be interpreted with caution.

Tinting and visibility

Benefits

Roper (as reported in Zwahlen and Schnell 1994) used square targets of 40.64cm side length and uniform reflectance of 0.075 to be detected at night through a clear windscreen of 88% transmittance and a tinted windscreen of 73% transmittance. The results of the study showed that using a clear windscreen, initial target detection distances of 76-123m were obtained. When the tinted windscreen was used night-time detection distances were reduced by 5%. From this work, Roper concluded that daytime heat absorbing benefits outweigh the loss in visibility at night.

A study by Rompe and Engel 1987 (in Taylor undated) found that for low contrast objects at night, subjects with spectacles have poorer detection rates, times and distances than those with normal eyesight. However for high contrast objects, detection was good for both those with and without spectacles. From this it was argued that the benefits of tinting can be gained by applying it to the rear window and since only high contrast objects (e.g. approaching headlamps) are seen at night, transmission levels of 40% are acceptable in rear windows. Even when the rear window transmittances were combined with mirror reflectance losses, which reduced the luminance available to the driver to 12%, test performance was still acceptable.

Prof. Stephen Dain (in Mukherjee 1997) suggests that side window tint levels to a minimum of 35% are acceptable and Mukherjee refers to BS EN 1836:1997 which permits sunglasses to have luminous transmittances as low as 8% for daytime driving (see table 6 in section 3).

However there may be incidents when the detection of low contrast is important eg detecting a pedestrian when reversing at night, and therefore the 40% transmittance proposed above may not be acceptable.

Disbenefits

Contrast effects*:* A report for the Virginia General Assembly concluded that '…window tinting reduces the ability to detect targets that would be difficult to see through untinted glass, and that this could be a safety liability, especially when ambient light is low'. (Proffitt et al. 1994). This is supported by Sayer and Traube, who in their

1994 review of visibility research, stated that 'The existing literature appears to leave little doubt that motor vehicle window transmittance (no levels specified) can influence a drivers' ability to detect objects/obstacles, particularly in dusk or night-time conditions.' US NHTSA suggests that at twilight a driver is twice as likely not to see a minimal contrast object, such as an unlit bicycle, through 50% transmittance compared to 70% transmittance (the generally agreed standard for windscreens and front side windows).

Rompe and Engel 1987 found that for low contrast objects on the road, accident risk increases greatly for low transmission windscreens (40%). Blackwell (in Hills 1976) similarly concluded that the poorer the visibility of an object, such as a pedestrian in dark clothing, the more detrimental the effects of tinting.

Physiological effects*:* Several studies have shown that reduction in visibility at low luminance levels is more pronounced for spectacle wearers. Weigt 1986 found that spectacle wearers have more inaccurate detections at low contrast levels with tinted windscreens. Rompe and Engel (in Taylor undated) found that low contrast objects have poorer detection rates, times and distances when viewed by spectacle wearers compared to those with normal eyesight. Rompe and Engel 1987 state that this phenomena is most noticeable for transmission levels below 77%. They conclude that the use of low light transmission windscreens (48% & 58%) for those who wear spectacles while driving is unacceptable.

The effects of age on vision when combined with tinting produce similar difficulties in detection at the threshold level (Allen et al 1996).

Driving effects*:* A number of studies have been undertaken to determine the affect of windscreen transmittance on various measures relevant to the driving task. Sayer and Traube 1994 in their research review stated that work by Derkum 1993, Heath and Finch 1953, Owens et al 1992, Rompe and Engel 1987 and Waetjen 1992 indicated the negative effects of reduced transmittance on target recognition and detection, visual acuity, reaction time and driving speed.

Target detection*:* Dunn 1973 (in Proffitt 1996) showed analytically that the probability of target detection decreases with reduced contrast and transmittance values. Contrast sensitivity decreases at a higher rate for transmittance values below 80%. Similarly a study for the Virginia General concluded that '..increased levels of window-tinting (from 88% to 13% transmission) were associated with an increase in the number of failures to detect a pedestrian in rear-view mirrors and with a decrease in the distance needed to detect this target' (Proffitt 1996).

Distance perception*:* A general conclusion by Haber 1955 (in Proffitt 1996) is that distance perception is reduced by tinting. Proffitt 1996 stated that depth perception was reduced by 25-30% when 65-72% filters were used. Research reported by Clark 1993 indicated that objects lit by direct and/or opposing headlights experience a 5-7% reduction in visibility distance. Pedestrians and cyclists (low contrast objects) experience a reduction in visibility distance of 30%. Olson 1996 quoted the findings of previous studies of the visibility distance for clear and tinted windscreens which showed comparative losses ranging up to 6% for tinted glazing whereas Doane and Rassweiler 1955 (in Proffitt 1996) found that tinting reduces detection distance by 3%. Both Heath and Finch 1953, who compared 89% and 71% transmittance, and Dunn 1973, who compared 96% and 78% transmittance, found a reduction in detection distance of 4.5m for reduced transmittance glazing. However Allen et al 1996.state that although losses in visibility distance may be relatively small, they are usually based on the detection targets being lit which is the condition where tinting has least effect on detection. A further study which suggests that detection distances may be underestimated in the literature is the statement by Hills 1976 that independent researchers have found the reductions in night-time seeing distances to be as great as 30-45%.

Visual acuity*:* Proffitt 1996 reports that visual acuity is reduced for targets when viewed through tinted glass. For transmission values of 65-72%, targets size needs to be increased by 10-20%.

A generalisation with respect to tinting, noted by Clark 1993, is that work supporting tinting is undertaken or funded by the motor industry whilst work by independent vision professionals does not support tinting.

Tinting and colour perception

Benefits

Hills 1976 states that colour vision, visual fields and stereoscopic vision have been shown to be of little or no significance for accident causation.

Mukherjee 1997 suggests that coloration issues can be addressed by using the sun glass standards BS EN 1836:1997.

Disbenefits

It can be shown that windscreens can selectively filter red wavelength and that rake, which increases the distance the light has to travel though the glass, intensifies this effect. Measurements of increased rake resulting in increased absorption are shown in the table below.

Table 1: Effect of windscreen rake on light absorption

	0°		**60 °**	
	White	**Red**	**White**	*Red*
Clear	88%	85%	79%	75%
Tint	73%	60%	65%	49%

Measurements with a Pritchard Spectra Photometer showed the following transmissions at 60°rake

The table above shows that the effect of tilting and tinting a windshield results in a greater loss of red light transmittance thus making brake lights and signal lights more difficult to detect (Allen et al 1996). Such an effect will be worse for protanopes (those who are red-colour blind) than those who are normally sighted. (A normal colour sighted person looking through a tinted windscreen will experience a reduction in red sensitivity similar to being a protanope. There is evidence to suggest that a protanopic driver wearing sunglasses looking through a tinted windscreen may not see any red light at all!). To compensate for the loss in colour sensitivity a protanope needs about four times the light intensity required by a normal observer to see a red light (Coles and Brown 1966 in Charman 1997).

Clark 1993 stated that spectrally selective sunglasses and tinted windshields may give a combined transmittance as low as 4%. The combination of windscreen, sunglasses and contact lenses has been investigated, but Dain et al (in Sayer and Traube 1994) were only able to conclude that the reduction in transmission presented a risk to drivers which they could not quantify.

Tinting and glare

Benefits

Sayer and Traube 1994 found no studies regarding discomfort glare, although Weigt 1986 quotes company car drivers using tinted windscreens who stated that they were not blinded by the headlights of other vehicles at night. However the sample size and the controls used in this survey are not known.

Disbenefits

Glare significantly effects detection and the closer the glare source the shorter the detection distance with dirty or scratched windscreens. Helmers & Lundkvist found that it was the increased levels of stray light resulting from the glare which caused the decrease in detection distances. However the detrimental effects of glare from oncoming vehicles are not reduced by transmission. Sayer and Trabue 1994.

Proffitt 1996 states that disability glare is not affected by transmission levels whilst Sayer and Traube 1994 indicate that there is no relevant research data concerning discomfort glare or veiling glare from reflections from the dashboard.

For sunglasses 50% luminous transmittance is given as upper limit therefore not achievable by windscreen. Adequate relief is a function of : wide-brimmed hats, sun visors and sun glasses which are readily removable. (Clark 1993).

Tinting and thermal comfort

Benefits

Mukherjee 1997 claimed improved thermal comfort during the daytime as a benefit of tinted windscreens which is in agreement with Hurst and Scroger 1974 (in Sayer and Traube 1994).

Work by Hills (1976) showed that in a moving vehicle in the daytime, a tinted windscreen reduced the interior temperature by 0.5-1.5^{o} compared to a vehicle with an untinted screen. However, manufacturers now supply glazing with solar properties to achieve temperature reductions without tinting.

Disbenefits

Hurst and Scroger 1974 (in Hills 1976) stated that windscreen tinting has a minimal effect on thermal comfort. The heat balance is largely affected by infrared against which the pigments used in the tinting have minimal effect.

Clark 1993 states that ‘occupant skin surface temperatures can result in discomfort due to a combination of direct solar radiation and high ambient temperature. Tinting (no level specified) can reduce this but effect is small and inadequate; light clothing, sun visors and air conditioning are more effective’.

Allen et al 1996 state that the maximum heat that glazing can reduce is 50% because 50% is supplied by visible light. The heat which is absorbed heats the glass and raises the temperature on both sides and then radiates heat. It is estimated that only 25% of the energy can be kept out of the car. Since the window area is responsible for less than 30% of the energy uptake, only 7.5% is eliminated by tinting (level not specified). It is suggested that a white-painted and insulated roof would remove up to 44%.

Tinting and privacy

Benefits

Tinting offers privacy and security and offers increased visual appeal (Mukherjee 1997).

Disbenefits

Clark 1993 found that for daytime, the apparent luminance of occupants is 85 to 65% for clear screens, but for 75% transmission windscreens this is reduced to 75% to 40%. While tinting offers increased privacy (although there is no literature which specifically addresses this Sayer and Traube 1994) and increased security for occupants, it is said to degrade road safety, encourage risky driving, reduces the ability for road users to make eye contact and limits the ability of the police to see into the vehicle. The study for the Virginia General Assembly concluded that '… in general, higher levels of window tinting made seeing inside a vehicle more difficult'. This resulted in concerns for patrol officers approaching vehicle in the course of their duties. (Proffitt et al 1996). This is in agreement with the work by Stackhouse and Hancock 1992 (in Sayer and Traube 1994) who examined the ability of approaching personnel to detect various objects, including a firearm, on the vehicle. They found that the subjects were sensitive to changes in the transmission level of the glazing and that this affected their ability to detect the firearm.

Clark 1993 found no literature to support the claim for increased buyer appeal.

Summary study

Many of the aspects discussed above are illustrated in the following case study. Four major manufacturers of after market films petitioned NHSTA for change in regulations to allow film to be applied to the side and rear of passenger car windows reducing transmission to 35%. The film in conjunction with 70% transmission already permitted results in transmission levels of 24.5%. NHSTA invited comment on this proposal from a wide variety of sources. The 78 responses from state agencies/departments dealing with transport safety and law enforcement are given in table 2 below.

Table 2: Questionnaire responses

Endangers law enforcers (cannot see weapons)	32
Prevents eye contact between road users	24
Reduced visibility in darkened conditions	24
General reduced visibility	22
Data promoting increased transmission is not sufficient	18
Current technology is sufficient re: health hazards eg absorbing radiation	17
Promotes criminality	14
Viewing forward traffic through rear window of car in front is impeded	11
Reduced visibility to those with poor eyesight	9
No guaranteed benefits re: reduction of UV, infrared, reduced temperatures etc	8
No guarantee of improved safety eg reduced laceration, prevented ejection	6
Reduction of glare, haze etc not guaranteed	5
Fashion accessory	3

It can be seen from the table that the main concerns are regarding the reduction in visibility out of the vehicle for the driver, particularly in darkened conditions, and a reduction in visibility into the vehicle for other road users (e.g. law enforcers, other drivers), which may encourage anti-social behaviour.

2.2.2 General findings

Rake angle and transmission

A document by Prof. Stephen Dain, University of New South Wales, (reported in Mukherjee 1997), indicated the following relationship between transmission level and rake angle. Refer to Table 3.

Table 3: Acceptable rake angle for given transmission levels measured perpendicular to the surface (in order to reach minimum windscreen requirement of 75% at normal incidence)

Transmission level	Rake angle (measured from vertical)
Untinted (92%)	67°
85%	61°
75%	20°

Smith and Bryant 1976 (as reported in Mukherjee 1997) showed that rake angles in excess of 60° from the vertical were common.

Recommended levels

Dunn 1973 (in Proffitt 1996) showed analytically that the probability of target detection decreases with reduced contrast and transmittance values. Contrast sensitivity decreases at a higher rate for transmittance **values below 80% (exact levels not specified).** Rompe & Engel 1987 (in Proffitt 1996) found increases in visual performance for spectacle wearers at levels **below 70% (58% and 40%).**

Weigt 1986 stated that a car glazed with a **windscreen of at least 75%, front-side windows of 70%, rear-side windows of 60% and a back window of 40%** is a good compromise between thermal comfort and driver vision. However the tests were conducted using a front windscreen rake angle of 35^{o} not 60^{o} which would reduce visibility performance further.

Rompe and Engel 1987 (in Taylor undated) suggested **40% to the rear**.

Prof. Stephen Dain (in Mukherjee 1997) suggests that tint levels to **a minimum of 35%** for side windows are acceptable.

2.2.3 Haze, Damage and Abrasion

Introduction

From the moment a car is first driven on the road, abrasions to the windscreens will occur. Damage to windscreens can be a result of windscreen wiper use, hand cleaning, ice scraping and small particles, such as stones and sand, hitting the windscreen (Allen, 1969, in Helmers and Lundkvist, 1988). An additional source of visual degradation when driving is a greasy layer/film that builds up on the interior surface of a windscreen. This layer has been attributed to a number of contamination sources including, atmospheric pollution drawn in when demisting or ventilating, internal pollution from smoking and food and in the earlier years of a vehicles life from particles given of from interior trim plastics under strong sunlight.

The resultant haze and abrasions on windscreens will increase the amount of stray light viewed by a driver. Stray light has been defined as the “light incident on a windscreen which is partially deviated from it's original direction by scattering from damaged areas of its surrounding surface" as opposed to useful light which is the "portion of light transmitted without disturbance". The measurement and effect of abraded windscreens have been discussed in a number of studies.

Haze

Allen 1974 (in Sayer and Traube 1994) stated that dirt contributes to reducing drivers visual performance especially under conditions of glare. Glare substantially effects driver visual performance when windscreens are worn (scratched) or dirty due to the stray light produced and the closer the glare source, the shorter the detection distance. (Sayer and Traube 1994). Owens et al 1992 (in Sayer and Traube 1994) note that the light scatter caused by glare is has a greater effect on acuity than age, target contrast or transmittance.

Rompe and Engel (1974) found that for low contrast objects on the road, the risk of accidents increases rapidly with untinted windscreens and haze effects of 1.2%. A further study in 1984 showed that the probability of detecting targets of varying contrast decreased from 91% with a clear windshield to 73% with a windshield having a moderate level of haze (Olson 1996). The probability decreased even more when a glare source was introduced.

Work reported by Weigt (1986) showed that a tinted windscreen of 77.4% transmittance and 1.5% haze performed on a par or worse than various tinted windscreens of illegal transmittance.

Rompe and Engel (in Weigt 1986) found for viewing objects at the lowest level of contrast through clear windscreens:

- No scatter 75% correct answers
- 1.5% scatter 55% correct answers

The research described above would suggest that haze has a serious detrimental effect on driver vision.

Damage and abrasion

Measurement of damage and abrasions

Allen 1969 showed a correlation between the number of miles driven and the number and severity of scratches resulting from wiper operation. At approximately 50,000 miles the windscreen should be replaced or re-polished to restore optimum vision at night against headlight glare (Allen et al 1996).

The problem of dirt and scratches on the windscreen was discussed by Allen et al. (1996). It was suggested that windscreen dirt and scratches can mainly be a problem at night when encountering glare. It is suggested that the windshield should be replaced or repolished to restore the optimum vision in order to protect from headlamp glare at night. A means for looking for scratch deterioration is suggested. This involves observing the reflection of the sun (or a stray light source) in the windscreen and seeing whether bright scratch rings show up around the image of the light source, which indicates an older windscreen.

An instrument used to measure scattered light across a windscreen in daylight is described in Timmerman (1986). The results of testing 250 cars using this stray light measuring device found a linear increase in the wear of the windscreens due to impact with small stones with mileage and a more than linear increase of wiper damage. However, it was stated that the level of wear varied among vehicles of identical mileage depending upon the type of use (e.g motorway, urban, country roads).

Allen (1974) undertook tests to determine the amount of surface dirt and damage on a population sample of vehicles. The results of these tests revealed that dirt and abrasion were common in the sample, with windscreen wiper abrasions being particularly prevalent.

To measure stray light caused by windscreen abrasion, a stray light analyser was used by Haase et al. This enabled two values to be found. Firstly, a mean value of the area of the windscreen which is affected by general haze, and a peak value, which is due to scratches and wiper damage. It was found that both mean and peak values increased with the mileage of the car.

Chmielarz et al (1988) also used a stray light analyser to obtain measurements of windscreen damage in selected regions of Germany and Sweden. Significant regional differences were found, contributions to these differences being made by weather conditions, geographical differences and road conditions, which increase the wear to windshields. Other factors which were found to increase the amount of wear included mileage, parking behaviour (garaged better than on the street) and also age. Younger drivers in Germany had vehicles with higher stray light indexes. Reasons given for this were that younger drivers do not keep large enough distances to preceding cars or that they are less likely to be able to afford more recent cars. For these drives, variables such as windscreen cleaning habits, smoking habits and the types of roads used by the driver (e.g. city, country roads, motorways) did not make a difference to the amount of windscreen wear (which contradicts the findings of Timmerman, 1986).

Green and Burgess (1981) also measured stray light levels to investigate the effect of worn windshields on driver visibility. Stray light levels were measured using a special measuring instrument similar to the stray light analyser used in the previous studies and also using a laboratory method. The results were compared so that the reliability and validity of the measuring instrument could be investigated, which were found to give similar results to the laboratory method.

The effect of abraded windscreens

Allen 1974 (in Sayer and Traube 1994) reported that windshield wear contributed to reducing driver visual performance under conditions of glare. This is due to the stray light produced by the windscreen. Derkum 1991 (in Sayer and Traube 1994) measured 28 vehicles windscreens in various conditions of wear and found moderate-to-high negative correlations between the measurement of scattered light and visual acuity.

Rompe and Engel 1984 and 1987 (in Sayer and Traube 1994) showed that target detection is reduced and speed decreased due to the stray light caused by worn screens. Helmers and Lundkvist 1988 (in Saye and Traube 1994) found that stray light from worn windscreens reduced driver visual performance between 9-25%.

Chauhan and Charman discuss the Mandelbaum effect and the implications it may have on night driving. The Mandelbaum effect occurs when it seems impossible to focus on something in the distance when viewing it through a screen. This could be because given the choice of two targets, a distant one (i.e. the road) and a nearer one which is at the tonic accommodation level (dark focus, resting state) (i.e. the windscreen), the eye will prefer the latter (Owens, 1979, 1984, Adams and Johnson, 1991, in Chauhan and Charman). Testing was carried out to investigate the Mandelbaum effect using both clear and abraded windscreens. However, it was found that rain and scratches produced negligible changes in the accuracy of driver’s focusing.

Kessler (1993) discusses how the deterioration of automobile glazing causes stray light by transmission or reflection and how this can affect what the driver can see through the windscreen. Scattered light can often produce “ghost images”, i.e., images of glare sources (e.g. headlights) seen by the driver in other parts of the their field of view, so instead of seeing one glare source, the driver will see two, the original glare source and the same glare source deflected off the windscreen.

The effects of the windscreen damage on static and dynamic driving tasks were measured and an evaluation into how practical resurfacing the damaged windscreen would be was undertaken (Allen, 1974). The results revealed that dirt and abrasion tended to interfere with the view of the road at night. A recommendation was made to increase public awareness of the problem of windscreen damage and replace or resurface windscreens when considerable damage occurs.

The effect on readadaption times (using a Landolt ring) after being dazzled by a bright light source when looking through a worn screen and a new screen were investigated (Timmerman, 1986). The results revealed longer readadaption times when using a worn screen than a new screen.

Pfeiffer (1970) also found reaction times increased as the level of stray light from a windscreen increased when detecting objects in a static simulation of an opposing situation between two vehicles.

Green and Burgess (1981) undertook a study to investigate the effect of various degrees of windshield damage on participants’ response time to safely proceed and on the rate of errors when viewing a road scene at night. Four degrees of damage were used in the tests; undamaged, chipped, moderately damaged and severely damaged. It was found that the rate of errors did not increase as a result of an increase in the severity of windscreen damage, however response times did increase (by up to approximately 8.5%). When adding a glare source to the road scene (i.e. simulated vehicle headlights), error rates were still not affected, but response times increased even more (by up to a further 5%).

Green and Burgess (1981) also reported on an accident study carried out by the Highway Safety Research Institute in 1978 called the Collision Performance and Injury Report (CPIR). Of 9218 accidents studied, only 39 (0.4%) were reported to have a visibility limitation due to the windscreen condition which was considered to be a potential causal factor of the accident. Two of these were reported to have damaged windscreens prior to the accident which were considered a contributing cause. It was concluded that windscreen damage (e.g. chips and pits) was not the major cause of any of the accidents. Abrasion was not assessed as part of this study.

As part of a series of tests, Timmerman (1986) carried out a test to investigate worn windscreens at night using Scattered Light Index (SLI) as a measure. Object recognition distances were found to be 7% worse with a windscreen of mean SLI of 1.7 than with a new windscreen (equivalent to a vehicle with a mileage of over 155000miles). Peaks with an SLI of 5.0 were found to be mainly caused by wiper damage. Subjective questioning was also undertaken, which found that a mean SLI of 0.7 or worse was considered to be unsafe for further use (equivalent to a vehicle with a mileage of 103000miles).

Tests were also carried out by Haase et al. (undated) to investigate the effect of the level of stray light from a windscreen on visibility distances of various objects when encountering an oncoming vehicle. Visibility distance decreased as the stray light index increased and was worsened when the oncoming vehicle low beams were incorrectly positioned. It was concluded that windscreen wear could be a potential contributor to night time accidents as the results show that it causes a reduction in vision at night.

Helmers and Lundkvist (1988) carried out a series of four full-scale experiments into the effect of windscreen damage on object detection distances when viewing lights from on opposing vehicle. The first investigated whether detection distances decreased when introducing a new windscreen compared to having no windscreen at all due to stray light. The results found that there was a small decrease in detection distances with a new windscreen (97 -98% of no windscreen condition). The second trial looked at differences in detection distances between a new and a worn windscreen. The worn windscreen was found to reduce visibility considerably, particularly when opposing lights were on low beam, as opposed to parking lights, and the target was dark.

The aim of the third experiment was to investigate whether any differences could be found between windscreens of similar wear in terms of visibility performance. The differences between the two worn windshields (SLI values of 3.04 and 2.50) were very small. The final experiment investigated whether a relationship between the SLI values of windscreens and target detection distances (under headlight illumination) could be found. Detection distances decreased as the SLI values increased, the decrease being more severe as the glare source increased in intensity, and the relationship was found to be approximately linear.

It was concluded that target detection distances were reduced (by 9% to 25%) by an increase in windscreen wear (up to 3.04 mean SLI – equivalent to a vehicle with mileage of over 155000 miles - see Timmerman, 1986), bright opposing glare sources and darker targets.

2.2.4 Reflectance

Sayer and Traube 1994 state that no studies with respect to windscreen reflectance were found. The only additional documentation found by ICE was Allen et al 1996 which provided some general discussion concerning reflection namely that it reduces contrast and increases glare and can be reduced by covering the vehicles dash with a dull black cloth.

2.2.5 Screen bands

Little research was found concerning the performance of screen bands. A report for the US Department of Transportation, NHSTA, entitled ‘The effect of light absorbing media on driver visual performance’ recommended that shaded bands should not be used unless they do not enter the drivers line of sight. This is because their intended purpose is to reduce glare; they are not designed to work in the same way as sunglasses. Shaded bands do not protect the retinal damage which can be caused by wavelengths of 400-1400 nanometers which pass through vehicle glazing. The reduction in discomfort caused by looking though a shaded band, opposed to a clear or tinted windscreen, may not sufficiently discourage a driver from looking towards the sun e.g. when waiting for a traffic light signal to change, and so may result in retinal damage.

2.2.6 Conclusions to driver vision

The research concerning the influence of various aspects of vehicle glazing on driver vision indicates that there is little accident data regarding its effects on road safety. However, what limited data is available suggests that windscreen damage (e.g. chipping and pitting) is the cause of very few accidents (Green and Burgess, 1981) whereas tinting is likely to increase the night-time accident rate (Clark, 1993).

One aspects of vehicle glazing, tinting, is the subject of much debate regarding the extent to which its benefits outweigh its disadvantages when in use on the road. Tinting, which has been the focus of much research in the 1980s and 1990s, appears to be a particular problem for low contrast objects viewed under low ambient lighting conditions (dawn, dusk and twilight) and this is especially the case for spectacle wearers (e.g. at 48% and 58% transmission, Rompe & Engel, 1987). It has been suggested that wearing spectrally selective sunglasses while viewing though tinted windshields may give a combined transmittance of as low as 4% (Clark, 1993) while the work of Morris et al. (1991) suggests that combinations of materials (e.g. sunglasses & screens) must not go below 12.5%. Both of these findings in some way conflict with BS EN 1836:1997 which permits sunglasses to have luminous transmittances as low as 8% for daytime driving. Experimental work has found that tinting reduces detection rates and increases detection distances and can also reduce the ability of drivers to perceive red lights.

As well as front windscreens, suggested minimums were given for side and rear windows. A minimum side window tint levels of 35% has been suggested (Dain in Mukherjee, 1997), as has 40% to the rear (Taylor, undated). A car glazed with a front-side windows of 70%, rear-side windows of 60% and a back window of 40% (plus a windscreen of at least 75%) has been reported as being a good compromise between thermal comfort and driver vision (Weigt, 1986). However, in a survey undertaken by the NHTSA, inviting comments about a proposed reduction in transmission of side and rear car windows to 24.5%, concerns were expressed about compromise in safety for both the driver (reduced vision out of the vehicle) and for other road users (reduced vision into vehicle, thereby encouraging anti-social behaviour).

Tinting does offer some reduction in interior temperatures but it is unlikely to be as effective as other means. Tinting also offers increased privacy although this may be detrimental to the eye contact made between road users and to the police when approaching vehicle occupants. Little research has been conducted with respect to glare but tinting is thought to have little effect, if any.

Haze probably has a more detrimental effect on driver vision than tinting. It was reported that a tinted windscreen of 77.4% transmittance and 1.5% haze performed, when detecting targets, on a par or worse than various tinted windscreens of illegal transmittance (e.g. 40%)(Weigt (1986).

Damage and abrasion are also problematic, particularly from windscreen wipers, hand cleaning, stones and dirt although it depends on the extent and type of exposure. The Highways Safety Research Institute (in Green and Burgess, 1981) concluded that windscreen damage was not the major cause of any of the accidents in its study, while Haase et al. (undated) concluded that windscreen wear could be a potential contributor to night time accidents as the results show that it causes a reduction in vision at night. Visibility through a worn windscreen was also found to reduce considerably in the presence of a glare source when viewing dark targets (Helmers and Lundkvist, 1988).

With damage, it takes longer to see (up to 8.5%), which again increases with a glare source (a further 5%)(Green & Burgess, 1981).

Little data was found regarding reflectance, although Allen et al. (1986) reported on the negative effects it has (e.g. reduce contrast and increase glare), which can be reduced by covering the vehicle's dashboard with a dull back cloth. Similarly, little was found regarding screen bands, except that they should not be used in the same way as sunglasses, as this could result in retinal damage (NHSTA, 1973).

2.3 Alternatives and new developments

2.3.1 Alternatives

Reverse tilt windscreen

The problems described in the preceding sections concerning glare, thermal discomfort, etc all arise from the rearward slope of the windscreen which has arisen due to the need for aerodynamic performance. If the angle of tilt of the windscreen was to be reversed this would:

- minimise reflections since the glass would reflect the shaded inside portions of the roof,
- shield against the glare from the reflected light caused by the windscreen dirt,
- be less prone to the effects of frost, collect dew or trap airborne dust on outside,
- be easier to clean inside,
- assist in reducing vehicle lift. (Allen et al 1996).

Vehicle and people treatments

A combination of vehicle and people treatments could be employed to alleviate some of the problems caused by current windscreen design.

Thermal reductions can be achieved, for example, by a white roof paint plus roof insulation which would eliminate at least 44 per cent of the solar radiation uptake (Allen et al 1996). This effect can be improved by appropriate use of light clothing, sun visors, wide brimmed hats, sunglasses and air conditioning. This is more effective than the benefits offered by tinting and more flexible according to the ambient conditions. Clarke 1993.

2.3.2 New developments

Two stage visors

A recent development with respect to motorcycle visors is the Lazer Revolution (see Appendix 8 for picture). This helmet has an integral sun shield which can be raised and lowered in front of the clear visor (from the rider's view). This is activated by way of a slider on the top of the helmet and, according to the manufacturers literature, can be used one handed by a gloved hand in less than a second. When the clear lens is in position, the luminous transmission is 78%, with the tinted visor it is 20%.

Light sensitive glazing

'Research Frontiers' proprietary suspended particle device (SPD) technology enables users to electronically and precisely control the passage of light through, windows, sunroofs, sun-visors, mirrors and eyewear, as well as enabling brighter easier to read flat panel displays for computers and other products. SPD film can be controlled automatically by means of a photocell or other sensing or control device, or adjusted manually by the user.' (Research Frontiers Press Release).

The film (activatable material) is laminated between glass or plastic which have transparent, electrically conductive coatings on their inner surfaces which contact the film. When low-current AC voltage is applied to the film the light absorbing particles within the droplets comprising the film align themselves to produce a clear film. If no voltage is applied the particles lie randomly within the droplets and the film is dark blue. (It should be technically possible in the future to produce black or grey). The extent of light transmission is controlled by the amount of voltage applied. No information was received from the manufacturer about fail safe conditions in the event of equipment failure.

If such a technology could be widely applied in vehicle glazing and rider eye protection the benefits of reduced transmittance by day could be employed without giving rise to disbenefits in conditions of lower ambient illumination.

The same technology appears to be under review by Setra, part of EvoBus, specifically with respect to glazed roof panels in coaches. Due to confidentiality, investigations as to the suitability of this technology for windscreens has not been discussed.

Pilkington is also investigating the use of electrochromatic systems with specific reference to vehicle applications.

2.3.3 Water and dirt resistant windscreens

An article by Snooks (1988) looked at the latest window and mirror technology including water and dirt resistant windscreens. These work by applying a special solution which diffuses into the surface of the windscreen and prevents raindrops joining up to form a film. At speeds above 40mph, these drops are blown away by the airflow. As well as raindrops, other benefits to using this solution is that it can help to reduce insect contamination and reduce wiper blade wear.

3.0 Standards

A précis of the legislative literature pertaining to vehicle glazing, windscreen repair and motor cycle helmet visors is given in Appendix 2. It pays particular reference to the visual/optical properties required and the processes of approval testing. The same information is summarised below in a tabulated form.

3.1 Standards reviewed

3.1.1 Vehicle glazing

- ISO 3537:1993(E) Road vehicles – Safety glazing materials – Mechanical tests
- ECE Regulation No.43 Uniform provisions concerning the approval of safety glazing and glazing material
- Council Directive 92/22/EEC Safety glazing and glazing materials on motor vehicles and their trailers

3.1.2 Automotive windscreen repair

- BS AU 242a:1998 Automotive windscreen repair – Code of practice
- BS AU 251:1994 Specification for the performance of automotive laminated windscreen repair systems
- The M.O.T Inspection Manual – Windscreens

3.1.3 Motorcycle helmet visors

- ECE Regulation No.22 (incorporating 05 series of amendments) Uniform provisions concerning the approval of protective helmets and of their visors for drivers and passengers of motor cycles and mopeds
- BS 4110:1999 Specification for visors for vehicle users

3.1.4 Motorcycle goggles

- BS EN 1938: 1999 Personal eye protection – Goggles for motorcycle and moped users

3.2 Summary of Standards

Table 4: Optical performance values for vehicle glazing

Optical property	**Windscreens** *(ECE Reg. No. 43)*	**Performance of automotive laminated windscreen repair** *(BS AU 251:1994)*	**The M.O.T Inspection Manual - Windscreens**
Luminous Transmittance. Light transmission	>75% windscreens >70% windows other than windscreens *(9.1.4.1)*		
Identification of colours	When a windscreen is tinted the following colours shall be identifiable:- *(9.4)* White - selective yellow - red Green – blue - amber		

Optical distortion	A windscreen type will be considered satisfactory if optical distortion does not exceed:- *(9.2.6)* • 2′ of arc (M1 category vehicle, windscreen zone A) • 6′ of arc (M1 category vehicle, windscreen zone B) • 2′ of arc (M and N category vehicles, windscreen zone I)	Optical distortion of the repaired area shall not exceed 2′ of arc. *(8.6)*	Light surface scratching in a concentrated area which obscures vision if it meets the fail criteria. (i.e. seriously restricts the driver's view). *In Zone A* (this is a zone of 290mm width, centred on the centre of the steering column and within the swept (wiper) area of the screen) the screen can be rejected if: • Damage is not contained with a 10mm diameter circle, • A windscreen sticker or other obstruction encroaches more than 10mm, • A combination of minor damage areas which seriously restricts the driver's view. In the *remainder of the swept area*: • Damage not contained within a 40mm diameter circle, • A windscreen sticker or other obstruction encroaching more than 40mm Repaired screens should be judged as original unrepaired windscreens. An invisible or barely detectable repair, finished flush with the surrounding glass, does not count as damage even if it exceeds the limits given above.
Secondary image separation	A windscreen type shall be considered satisfactory if secondary image separation does		

	not exceed:- *(9.3.5)* • 15′ of arc (M1 category vehicle, windscreen zone A) • 25′ of arc (M1 category vehicle, windscreen zone B) • 15′ of arc (M and N category vehicles, windscreen zone I)		
Resistance to abrasion Light scatter (%) Light diffusion $(cd/m^2)/lx$	Resistance to abrasion will be considered satisfactory if the light scatter as a result of abrasion does not exceed:- • 2% for laminated glass windscreens *(Annex 6)* • 2% for laminated glass panes *(Annex 7)* • 4% for safety glass panes faced with plastic material *(Annex 9)* • 2% for the outer face of glass/plastic windscreens and panes and • 4% for the inner face of glass plastic windscreens and panes *(Annex 10 and 11)*	The mean value of the light scatter through four repaired areas shall be not more than 4% above the value of the light scatter through the base glass. *(8.7.1).* 8% after exposure to high humidity. *(8.7.2).*	

Resistance to radiation	Total light transmittance does not fall below:- • 95% of the original value before irradiation for windscreens; • 70% in the case of panes other than windscreens • 75% in the case of windscreens in the zone *(9.2.5)* where regular transmittance is measured *(6.3.1.1)*	The total luminous transmittance of the repaired area shall be >95% of the original value before irradiation, and not less than an absolute minimum value of 75%. *(8.4)*			Following irradiation the relative change in the luminous transmittance shall be less than ±5% for filters of category 0, less than ±10% for filters of category 1 and less than ±20% for filters of all other categories. *(4.6)*

Table 5: Optical performance values for visors, goggles and sunglasses

Optical property	**Visors** *(ECE Reg. No. 22 - incorporating 05 series of amendments)*	Visors *(BS 4110: 1999)*	**Goggles** *(BS EN 1938:1999)*	**Sunglasses** *(BS EN1836:1997)*
Luminous Transmittance. Light transmission	Visors shall have a luminous transmittance $\tau v \geq 80\%$, relative to the standard illuminant D65. A luminous transmittance $80\% > \tau v \geq 50\%$ is also permissible if the visor is marked 'For Daytime Use Only'. *(6.15.3.4).*	Filter category 0 shall have a luminous transmittance τv of 80 to 100%. Filter category 1 shall have a luminous transmittance τv of 50 to 80%.	18% to 80% depending on filter category (see table 6 below)	3% to 80% depending on filter category (see following below). Note: 3-8% not suitable for driving and road use.
Spectral Transmittance	For wavelengths between 500nm and 650nm the spectral transmittance of the visor shall not be less than $0.2\tau v$. *(6.15.3.7)*	For wavelengths of 280-315nm, filter categories 0 and 1 shall have a maximum spectral transmittance of $0.1\tau v$. For wavelengths of 315-380nm, filter categories 0 and 1 shall have a maximum spectral transmittance equal to τv.	As BS EN1836:1997	For wavelengths between 500nm and 650nm the spectral transmittance of filters suitable for road use and driving (categories 0, 1, 2, or 3) shall be not less than $0.2\tau v$ *(4.1.2.2)*

Recognition of signal lights. Relative attenuation quotient (Q)	• 0.8 for red and yellow signal lights • 0.6 for green signal light • 0.4 for blue signal light	Q ≥ 0.8 for red, yellow, green and blue signal light recognition.	As BS EN1836:1997	The relative visual attenuation quotient Q of filters of categories 0, 1, 2, and 3 shall be:- • >0.8 for red and yellow signal lights, • >0.6 for the green signal light • > 0.4 for the blue signal light *(4.1.2.2.2)*
Identification of colours				The relative visual attenuation quotient of filters of scale numbers 5-1.1 to 5-3.1 and 6-1.1 to 6-3.1 (suitable for driving) for signal lights red, yellow, green and blue shall not be less than 0.8 *(BS EN 172:1994 - 4.2.3)*.

Resistance to abrasion Light scatter (%) Light diffusion $(cd/m^2)/lx$	The light diffusion before abrasion shall not exceed 0.65 $(cd/m^2)/lx$ (test method a & c) or 2.5% (test method b) *(7.8.3.2.1.2)* **Note:** Reg 22 Abrasion test is by falling sand method and completed when 3 kg of sand have been projected through a gravity tube). Luminous transmittance measured after the test must not be less than 75% of the pre-test values.	Following UV conditioning and abrasion the visor samples shall show a light scatter value not greater than 10% on either surface *(BS 4110:1999 5.5)* **Note**: Abrasion test by revolving wheel method for 100 cycles)	Light diffusion before abrasion = Single lens goggles (Type A) not to exceed 1 $(cd/m^2)/lx$. Multiple lens goggles (Type B) not to exceed 2 $(cd/m^2)/lx$. *(Table 1)* After abrasion test the goggles oculars shall have a reduced luminance factor of not more than 12 $(cd/m^2)/lx$. *(4.7.2)*	When tested the reduced luminous coefficient of the filters in the new state shall not exceed the value of 0.65 $(cd/m^2)/lx$ *(4.3)*

Resistance to radiation				Following irradiation the relative change in the luminous transmittance shall be less than ±5% for filters of category 0, less than ±10% for filters of category 1 and less than ±20% for filters of all other categories. *(4.6)*

Table 6: Sunglasses and goggle filter categories *(Table 1 EN1836:1997 and Table 2 EN 1938:1999)*

Filter category	Description	Range of luminous transmittance(τv) %	
0 Sunglasses	Clear or very light tint	80	100
1 Sunglasses	Light tint	43	80
2 Sunglasses	Medium tint	18	43
3 Sunglasses	Dark tint	8	18
4 Sunglasses	Very dark tint Not suitable for driving and road use	3	8
1 Goggles		80	100
2 Goggles		43	80
3 Goggles		18	43

3.3 Rationale for existing Standards

Although an extensive literature review was conducted, which identified previous research investigating the effects of degradation on the optical properties of vehicle glazing and motor cycle helmet visors, no published evidence of any previous research having influenced the current legislative performance conditions was found. However it can be seen that there is some similarity between the standards and the preceding research. Similarly, consultation with personnel involved on the various Standards Committees did not identify the scientific basis on which current EC or BSI approval is granted. Reference is made in a DETR document submitted to the BSI visor committee to research carried by TRL in 1983, which influenced the original lowering of the minimum visor luminous transmittance value from 80% to 50%. However this research was not published and so the rationale for the limits is not known to those who were not party to the BSI discussions. As a result of this research and related consideration, a minimum luminous transmittance of 50% was considered to be an appropriate balance between the benefits of tinting in bright conditions and the risks of inappropriate use. No rationale has been found to justify any further reduction below 50%.

4.0 Accident data

4.1 STATS 19

It was proposed that the extent of any road safety issues, caused as a result of poor quality drivers/riders vision, might be assessed through the investigation and analysis of accident data. This methodology has proved unsuccessful or inconclusive for any accident database using the STATS 19 form as its input. Whilst many vehicle, weather and road environment conditions are recorded, no opportunity is provided for gathering information regarding specific vehicle components unless the attending officer has added additional written notes. These notes are not coded and for this reason are not retrievable through database interrogation.

4.2 TRL fatals database

The Transport Research Laboratory (TRL) maintains a database of road traffic accidents involving fatalities. This is compiled using old police reports which contain full details of the accident. Again, details relating to the condition of vehicle glazing or motor cycle crash helmet visors are not entered on the database. Data from this database has been provided and this is reported with other survey information in the section relating to the views of interested parties.

4.3 The Glasgow database

This database is held at TRL and records motorcycle accidents where the rider sustained a head injury. Pre 1994 only accidents involving fatal head injuries were recorded, but since then non-fatal head injuries have been included - data entry ended in February 1998. No information about the visor used at the time of these accidents was entered on to the database but a sample of the visors underwent an investigation for evidence of misuse (tinted visors used at inappropriate times). Only one relevant accident was found which involved a lightly tinted and abraded (scratched) visor which was used at night.

4.4 Association of Chief Police Officers ACPO

ACPO Traffic Committee stated that driver vision is an area of concern for them. However this was predominantly focussed on aspects of driver eyesight rather than visual interaction with/through vehicle components. Some forces however do have an active interest in this latter area with respect to both riders and drivers and these are discussed below. In general all the UK forces were unable to provide any accurate statistical information, or incident reports in sufficient number, to assist in quantifying those aspects of driver/rider vision which are of concern to this study.

4.4.1 South Yorkshire Police

South Yorkshire Police Accident Investigation Branch have compiled a database of over 200 cars which have been stopped for having side and rear window light transmittance values less than 70%. Roadside testing is now possible with a portable, hand-held device called “Tintman”. While none of these vehicles were involved in road traffic accidents, there is evidence that an accident involving a car pulling out in front of a motor cyclist was due, predominantly, to the fitting of tinting film to the side windows. It is believed that the light transmittance value of the side window, through which the car driver failed to notice the oncoming motorcyclist, was about 16%. South Yorkshire Police AIB have provided data from their own survey of motorcycle visors which is reported with other survey information in the section relating to the views of interested parties.

4.4.2 Suffolk constabulary

Suffolk Constabulary considered the observed increase in the number of vehicles on the road with tinted glass to be a threat to road safety and undertook an enforcement campaign. Whilst they stated that their prosecution level was at 65% luminous transmission they found that any glass which appeared dark enough to warrant investigation usually had a luminous transmission level of 35% or less. Several prosecutions have also taken place in relation to the use of darkened, non-compliant crash helmet visors. Whilst Suffolk Constabulary are aware that the sale of these visors is also prohibited, they consider the current arrangements regarding this to be ineffective due to the large numbers of such helmets in use on the road.

4.4.3 Greater Manchester Police

Responses from the Accident Investigation Unit at Greater Manchester Police indicate their concerns that abrasion and misting are the main problems with respect to motorcyclists' vision.

4.5 Automobile Association AA

The response from the AA was that the areas of investigation within this study are not aspects about which AA members complain. The only reference which they are aware of in this area is the TRRL 'on-the-spot' accident causation research of the 1970s which suggested that various windscreen defects contributed to about 0.6% of accidents.

More recently, investigations of their own, have lead them to conclude that:

- tinted windscreens should be avoided for use by older drivers,

- old windscreens which have become scratched or pock marked should be replaced.

No statistical information of relevance to this study was available.

4.6 Summary

Discussions with those given above and other interested groups have confirmed that quality accident data in sufficient number and regional coverage is not available for use without an investment in resources beyond the scope of this study. However such information is necessary if the cost-benefits of amending windscreen and visor design and use is to be determined. It is therefore recommended that investigations be made into the precise nature of the information required and how this may most effectively be obtained, followed by the establishment of a specific database for analysis. Initial investigations could be made as part of the On-The-Spot study currently being undertaken by the Department and STATS19 special projects.

5.0 Views of interested parties

A wide range of individuals and organisations with a specialist interest or expertise related to the scope of the project have been identified and approached by the project team. These include members of the relevant BSI committees, motorcycling organisations, window tinting companies, visor manufacturers, vehicle glazing companies, test houses and others undertaking research directly relevant to the project. Drivers and riders were also surveyed for their opinions. The list of contacts is provided in Appendix 4.

5.1 The current position regarding light transmittance of motorcycle visors

The current position of interested parties with regard to the issue of amending the regulations/standards covering the transmission levels of motorcyclists' eye protection is given below.

Colin Fowler (Vision Sciences Dept, Aston University) states in a letter to the committee, dated 1st September 1997, that the current 50% transmittance would not protect against sun glare. He cites BS 2724:1987 'Sunglare protectors for general use' which states that for protection from sunglare while driving, filters should have a transmittance of between 29.1% to 17.8%. However it has not been possible to identify the justification for these limits.

Ronald Rabbetts, a practising optometrist and member of the BSI committees PH/2 eye protection and PH/2/1 Sunglasses, contacted ICE to provide information on the theoretical benefits of tinting. A tinted lens, he states, reduces discomfort glare by a factor of its transmittance raised to the power of 0.6. Thus a pale tint with a transmittance of 85% reduces the glare to 0.91 of its previous value, 50% transmittance to 0.65 and 20% (a fairly dark sunglass but in the range allowed by BS EN 1836 for vehicle drivers) to 0.38 of the original glare index.

The members proposing or supporting this proposal recognised potential safety disbenefits and suggested the following provisos:-

- that Category 2 visors should not be used during darkness or conditions of poor visibility,
- that they should be marked 'For daytime use only' or the equivalent (a draft symbol was circulated for comment),
- that it be made a statutory offence under RVLRs to wear a Category 2 visor at night,
- that the means of attaching the visor to the helmets should be manufactured to enable easy fitting and removal without tools to encourage responsible use i.e. changing between 'clear' and tinted as light conditions change.

In addition, RoSPA considered Category 2 filter acceptable only for riders with good eyesight who did not wear spectacles or contact lenses.

The DETR, in a letter to BSI dated 26th Feb. 1998, set out in detail their concerns and reasons for opposing Category 2 filters. In summary DETR's objections are based on the lack of any new evidence to suggest that a compelling case can be made on grounds of road safety for a further reduction. A major concern is the issue of potential misuse, i.e. riders using darker visors during darkness and poor visibility. They also point out that when experiencing glare from low sun, the contrast between bright sun and normal light is such that adequate vision can only be achieved by obscuring the sun completely. DETR suggest that this is best solved by using a helmet or visor with a removable peak or perhaps by a visor with a graduated tint. (Bob Heath argues that such graduated visors do not address the issue of glare reflected from the road surface.)

The British Motorcyclists Federation has 130,000 member including affiliates, and over 12,000 individual members. Trevor Magner of the BMF and a member of the BS committee stated that while the BMF is interested in the tinting issue, it is not currently a high priority, campaigning issue. He believes that fogging (misting) is a greater issue than abrasion now that the new BS 4110 standard increases the abrasion resistance requirement. Mr Magner is concerned that anti-fog/mist surfaces may be too soft and vulnerable to scratching (interior surfaces) and that fogging may be a helmet design issue i.e. ventilation.

When revising BS4110, BSI visor committee members, with the exception the DETR, proposed and supported a reduction in the minimum eye protector luminance transmittance from 50% to 18%, known in the standards as Filter Category 2. However since the standard had to be consistent with national regulations, the minimum light transmittance in the revised BS remained unchanged at 50%.

5.2 Survey of drivers' views regarding quality of vision through car windows

A survey was undertaken to seek drivers views on the quality of vision through car windows. Face-to-face interviews were conducted with a random selection of drivers in the Loughborough area to seek information on their experiences of the effects of misting, glare, haze, abrasion and A-pillar design on visibility. The desirability of tinted windows was also explored as an additional means of probing the issues of sun-glare and dazzle.

This survey was conducted in two stages. The first phase was concerned with windscreen misting, cleaning, sun-glare, tinted windows and A-pillar obscuration. The second phase was concerned with windscreen abrasion, damage, repair and reflections. The survey sample details are given in the tables below. Full survey details are given in Appendix 5.

Table 7: Participant gender ratios

	Survey 1	
	Male	**Female**
	14	16

	Survey 2	
	Male	**Female**
	15	21

Table 8: Participant age and years of driving

	Survey 1	
	Age	Years driving
Average	42	23
Minimum	21	4
Maximum	72	54

	Survey 2	
	Age	Years driving
Average	47	25
Minimum	22	3.5
Maximum	75	55

Table 9: Age of vehicle

(Years)	Survey 1	
	Age of car	How long owned
Average	7.3	2.9
Minimum	2	0.1
Maximum	15	13

	Survey 2	
	Age of car	How long owned
Average	7.6	4.0
Minimum	0.5	0.25
Maximum	17	12.5

5.2.1 Windscreen misting

Two thirds of the drivers reported that their windscreen sometime or often misted up (21/30). As might be expected this mainly occurred under damp conditions (rain, damp occupants) and when the weather was cold. Cold early mornings being cited on a number of occasions.

Nearly all drivers clear the screen with the car's fan (20/22) and 7/22 said that they sometimes or often had to do this while driving. If this latter point is substantiated then it implies that a not insignificant proportion of drivers regularly drive with reduced visibility through the windscreen.

5.2.2 Windscreen cleaning

The film of dirt which gradually accumulates on the interior surface of the windscreen not only reduces light transmission but also encourages moisture to

condense on the screen leading to misting. The dirt film also causes a proportion of light passing through the screen to be scattered resulting in a veiling luminance (haze).
Of 26 replies, 7 drivers had cleaned their screen within the last week, 13 within the last month and 6 less recently than this. The majority (21/29) do not clean the screen regularly but just when they notice it is dirty. Whilst any conclusions which may be drawn from this must be tentative, given for example that we do not know at present the rate at which dirt accumulates on windscreens, we should consider that a significant proportion of windscreens could be suffering haze and misting unnecessarily.

Having stated the above, 23/30 stated that they rarely or never experienced problems with vision due to accumulated dirt on the inside of their car windows.

5.2.3 Windscreen abrasion

Of the 36 drivers who completed the questionnaire, 10 stated that at some stage in their driving experience, they had required a new windscreen to be fitted to a vehicle they had owned, the time elapsed since the last time this had happened ranging between 3 days and 20 years. When asked about the extent of abrasion on their current vehicle's windscreen, just over half of the drivers reported that their windscreen was not abraded at all (19/36). Of those who did report abrasion, 4 found their windscreen to be somewhat or very abraded.

Windscreen abrasion had caused vision problems for 5 of the 36 drivers, with it being a problem 'rarely' or 'sometimes'. Abrasion was said to cause vision problems when driving towards poorly adjusted headlights of oncoming cars, driving towards a low sun and looking through a misted windscreen. One driver suggested the abrasion was caused by use of the windscreen wiper. Only one respondent found abrasion to be more than a slight problem. Of the 5 respondents who found abrasion to be a problem, 3 were able to reduce the problem. This was achieved by de-misting the screen before driving away, using good quality wiper blades and using a compound to remove the scratches at driver's eye point.

5.2.4 Windscreen damage

Experience of windscreen damage was reported by two-thirds of the respondents (24/36). Chipped glass was the most commonly reported damage (19/36) with 5 drivers reporting larger cracks or shattering. The cause of the damage was mainly from road chippings or stones being thrown up by other vehicles (21/36) and also debris fallen from lorries (3/36). The damage was reported to be more often on the driver's side (13/36) than on the passenger side (3/36).

Of the 36 respondents, 6 had experienced problems with vision while driving at some stage in their driving experience which was believed to be caused by windscreen damage, but never very often. The type of conditions these problems were experienced under included wet conditions, dirty windscreen, sunny weather, dusk and viewing oncoming headlights. The problems associated with driving were rated as being either slight or somewhat but never severe. Problems with windscreen damage were reduced by 3 respondents, by either cleaning their windscreen regularly, getting the windscreen repaired or purchasing a new car.

5.2.5 Windscreen repair

Only 4 of the 36 of the drivers reported driving with a damaged windscreen that had been repaired. The repairs were on windscreen chips located on the driver's side. Two respondents had at some point experienced problems due to the repaired windscreen, these occurring in winter when light levels were low (i.e. dusk and dawn) and when very sunny, causing a distraction to the driver. When asked how severe the problem was, the same two respondents found the problem to be slight. One found a way to reduce the vision problems associated with a repaired windscreen was to keep the windscreen clean.

5.2.6 Windscreen reflection

Of the 36 respondents, 26 had at some time experienced problems due to reflection on windscreens, of which just under half (16/36) had experienced them at least sometimes. The time of day these problems were experienced the most was during the day (19/36), including dusk and dawn (4/36). Problems at night were reported by nearly ¼ of respondents (8/36). Of the 19 respondents who had experienced visual difficulties with reflection during the day, 18 reported the weather conditions to be sunny and/or clear. A further 6 drivers had difficulties with reflection under wet weather conditions. Other contributors to windscreen reflection were stated as: the dashboard/objects on dashboard and trees (8/36), driving towards a low or bright sun (10/36), oncoming lights (i.e. vehicle and street lights, 5/36), an unclean or smudged screen (3/36) and windscreen angle (1/36).

When asked how severe these visual difficulties with reflection were, 15 drivers reported that the problems were slight, and 10 found the problems to be either somewhat or very severe. A reduction in the visual problems associated with reflection was achieved by 14 of the drivers. The most popular methods used were by wearing sunglasses (5 drivers), by using the sun visor (4) and by removing objects from the dashboard (4).

5.2.7 Sun glare

Problems associated with bright sunlight while driving were experienced often or sometimes by 20/29 drivers, with 4 stating this was often a problem. However only 1 driver reported ever having had an accident or near miss due to this (when reversing out of their drive).

Remedial actions drivers take include using the cars' sun visors (16) and/or wear sunglasses (10).

5.2.8 Tinted windows

None of the respondents had had their windows tinted and of the eight who stated they had tinted windows they were all an OE light tint. Only one driver claimed that the tint influenced their purchase decision when buying the car, stating that as well as reducing glare it gave a degree of privacy.

If cost is ignored, 13/20 drivers said they would have tinted windows. For 9 of them this would include the windscreen, so as to reduce glare.

5.2.9 A-pillar obscuration

The ages of the cars in this small sample means that many of the respondents cars will not have the newer design of A-pillar, which tends to be thicker and more raked. This limits the extent to which conclusions can be drawn from this part of the survey.

11/29 drivers said that the A pillar sometimes or often restricts their vision out of the car and 14 stated that they sometimes or often had to move their head to see round it.

In order to assess whether drivers perceive the trend for increased thicknesses and rakes of A pillar as detrimental to vision, they were asked how the pillar on their current car compared with other cars they had driven. 10 stated it was the same, 8 that it was better and 5 that it was worse.

Two drivers reported near misses that they had experienced as a result of A pillar obscuration. One had had several near misses at T-junctions in several cars and the other had failed to see an approaching car at a roundabout.

5.2.10 Summary of drivers views

Of the aspects of driver vision mentioned in the remit of this project, problems with glare (which it has been suggested may be addressed by transmission levels) were found to be the most extensive. However drivers in this survey did not experience a significant problem with sun glare, which would motivate them to seek tinted windows.

The accumulation of road film on the interior of the windscreen (contamination) was the next most common cause of visual problems to drivers. The drivers interviewed did not clean their screens on a regular basis and this could have implications for the frequency of misting and ‘haze’.

Abrasion and damage caused similar degrees of visual problems, rated as slight or somewhat problematic, with screen repairs causing the least.

The information given above concerning the frequency of occurrence of the visual problem for drivers and the extent to which guidelines exist to advise drivers of unsafe levels was used to prioritise the issues addressed by the test programme.

5.3 Survey of motorcyclists' views regarding quality of vision

5.3.1 Trends in motorcycle ownership

In 1997 there were 626,000 licensed motorcycles in the UK, compared to 978,000 in 1987 (Transport Statistics Great Britain 1998). Over this ten-year period there has been a significant change in the types of machine owned. In 1987, two-thirds of licensed machines were under 125cc, in 1997 nearly two-thirds were over 125cc, with the largest single category being machines over 500cc indicating a dramatic shift in the composition of the motorcycle population. Refer to Table 10.

Table 10: Licensed motorcycles

Over	Not over	1987	1997
	50cc	352	96
50cc	125cc	347	143
125cc	150cc	4	1
150cc	200cc	39	12
200cc	250cc	78	44
250cc	350cc	13	10
350cc	500cc	46	54
500cc		99	265
All over 50cc		626	530
All engine sizes		978	626
		thousands	

We can speculate on the possible reasons for this shift in ownership; changes in the motorcycle driving test, fewer people using a motorcycle to commute to work and an increase in the number of older riders returning to motorcycling. The shift to larger machines may contribute to an increased market for tinted visors. The riders of more powerful and faster machines may have more disposable income, seek more ways of increasing their perceived safety and given the high-tech nature of modern motorcycling may seek out the latest technology in their protective equipment.

To help ensure that the scope of the testing programme addressed all the key issues, a survey was undertaken to seek riders views on the quality of vision through motorcyclists' eye protection systems. In order to obtain first-hand information about the perceived visual performance of the eye protection options currently available to motorcyclists, a small survey was undertaken of professional and non-professional riders.

Face to face interviews were conducted with 28 motorcyclists drawn from the general public in and around the Loughborough area. The professional rider sample comprised members of Nottinghamshire Police Traffic Section and the Automobile Association's mobile patrol officers. A postal survey was used for the professional riders.

Completed questionnaires were obtained from 28 members of the public (25 male, 3 female) and 14 professional riders (all male). Sample details are given in the tables below. Full survey details are given in Appendix 6.

Table 11: Age and years of riding

	General public		Professional	
	Age	**Years riding**	**Age**	**Years riding**
Average	41	15	39	20
Minimum	22	1	32	15
maximum	73	44	53	25

Table12: Size of motorcycles ridden

	General public	Professional
Up to 250cc	3	0
260 – 500cc	7	0

510 – 1000cc	16	1
Over 1000cc	2	13

Table 13: Use of motorcycle (multiple responses allowed)

	General public	Professional
Commuting	21	7
Professional	6	14
Leisure	34	14

Table 14: Frequency of riding

	General public	Professional
Daily	13	13
Weekly	11	0
Monthly	4	1

All the riders in the sample used visors and full faced helmets.

Having asked the riders how frequently they rode in different weather conditions they were asked an open question for any comments with a prompt for vision problems.

The main problems raised were:-

- *Misting* (5/14 professional, 3/28 public): particularly when riding slowly.
- *Rain* (5/14 professional, 1/28 public): water droplets on the visor, which caused light scatter and multiple images of car headlamps.
- *Glare* (in bright sunlight) (3/14 professional, 3/28 public).
- *Abrasion* problems were not spontaneously mentioned by any of the riders.

5.3.2 Misting

When asked specifically about misting most of the professional riders claimed that their visors suffered from it 'sometimes' or 'often' (13/14). A lower proportion of general riders suffered this problem (12/28) however this may reflect how often riders reported riding in the rain (13/14 professionals 'often' ride in the rain compared to 12/28 general riders).

Misting was reported as being a particular problem at slow speeds, where air circulation through the helmet is insufficient to clear the visor.

5.3.3 Glare

Sun glare was reported as a problem by a high proportion of both professional (11/14) and general (19/28) riders. Whilst the main problem for both groups occurs when the sun is low in the sky, the professionals also reported problems during bright sunlight when the road surface is wet.

Confirming the glare problem, 24/28 public and 11/14 professional riders stated that some form of glare reducing eye protection would be useful in conditions of low sun or bright sunlight.

With respect to tinted visors 12/28 of the general public and 1/14 of the professional riders stated that their visor was tinted (and at least one of these was used for racing). The range of tinted visors used reflects the current market and includes blue iridescent, gold, black, mirror finish etc). From the responses it would appear that 5/28 members of the general public and 0/14 for the professional riders have visors with luminance transmissions below the current required minimum.

Half of the riders in the sample have ridden with tinted visors at night time or in conditions of poor visibility (14/28 general public and 6/14 professional)
It is interesting to note that while only 1/14 professional riders is currently using a tinted visor, 8/14 have tried one at some time. The most frequent reason (and reported benefit) being to reduce glare. Seven of these eight riders reported the main disadvantage as being the reduced visibility at lower light levels (dusk, overcast sky and night time). Of all the riders, ten stated that the visor reduced their ability to see under these conditions. A further 2 stated that they adjusted their riding accordingly so it must be assumed that their vision was also reduced.

5.3.4 Changing from tinted to clear visors when visibility declines

Two issues raised by this option were addressed in the survey: how easy is it to change a visor and would riders be prepared to do it?

18/28 general public riders stated that they would be prepared to use tinted visors in bright daylight and change to clear when visibility was poor and at night time. A high proportion (11/14) of professional riders would accept this option, which may result from them having to ride in almost all weather conditions. However given that half of the sample have admitted to using visors illegally, these statements should be treated with caution.

It would appear that physically changing the visor is not generally a problem, with 34/38 riders who had ever changed their visor stating that the ease with which they could do it was at least 'acceptable'.

5.3.5 Alternatives to tinted visors

Nearly all the riders had used sunglasses as a means of reducing sun glare while riding (36/42). Three had used helmet peaks and only one had tried a sun-strip. The one benefit of using sunglasses as a means of glare reduction, reported by several riders in the survey, was the ability to put them on or take them off according to conditions.

The most frequent problem cited was the discomfort of wearing sunglasses under some helmets.

5.3.6 Abrasion

The riders did not appear to consider abrasion a significant problem with their visors. 13/14 professional riders and 19/28 of the general riders stated that scratches were 'rarely' or 'never' a problem. Given the average age of their visors (21 months) this must reflect upon the good abrasion qualities of the coatings used on current visors and the effectiveness of the current standard.

However it may be worth considering that as most abrasion will be the result of repeated cleaning and the effects of air borne abrasives, it is likely that riders will adapt to a degree of abrasion and may therefore be unaware of some degree of reduced vision.

5.3.7 Summary of riders' views

The high levels of abrasion resistance of modern materials means that scratched visors are no longer a significant problem for riders.

Misting however is a problem, especially when travelling at slow speeds.

Sun-glare, either direct when the sun is low in the sky, or when reflected off wet road surfaces is a significant problem. Some riders have used tinted visors in these conditions. However, they report that when doing so their vision under low light levels is reduced.

Sunglasses are a partial solution to the problem but can be uncomfortable when worn under a helmet.

5.4 Survey of visor usage

Sales figures give an indication of the numbers of different types of visor in use and the demand for tinting. Bob Heath supplied figures for their popular 2mm replacement visors over the last 8 years – 61% clear, 39% smoke (all BS4110ZA certified).

5.4.1 ICE Ergonomics survey

A survey of 100 motorcyclists was undertaken by ICE Ergonomics to estimate the extent of visor misuse. The transmission level of each visor was measured using the Tintman – vehicle window transmission meter, a technical instrument used by a number of police forces to measure window and visor transmission levels.

With respect to the transmission levels, the survey findings were that:

- 80% of visors had transmission levels above 80%.
- 9% had transmission levels between 50% and 80% (daytime use only level)
- 11% had transmission levels below 50% (below permitted transmission levels).

Indirect questions were asked to determine if the visor would be used after dusk on the night of the survey. Of the 20 respondents whose visor transmission levels were below 80% i.e. below the level currently regulated as being suitable for use in conditions of low light, all stated that they would be riding home at dusk or later. Only one respondent who had a daytime usage visor carried a spare; however this was also a daytime use only visor.

It can therefore be concluded that from the sample of 100 motorcyclists, there was a 20% misusage rate comprising of 9% who would use daytime visors in inappropriate conditions and 11% whose visors were less than the currently regulated daytime levels. In addition it was found that:

- of those 31 riders who often ride in the dark, 9 had visors of inappropriate transmission levels,
- of those 48 riders who sometimes ride in the dark, 7 had visors of inappropriate transmission levels.

Refer to the tables below for additional information.

Table 15: Visor age and miles travelled

	Mean	**Min**	**Max**	**SD**
Age of visor in years	1.59	0.02	8.00	1.62
Miles per year	6255	1000	15000	2656

Table 16: Frequency of riding in various conditions

	Often	Sometimes	Rarely	Never
Rain	26	52	17	5
Darkness	31*	48**	17	4
Sunlight	92	8	0	0
Fog/mist	7	35	49	9

* Of the 31 respondents who often ride in darkness, 9 had visors of inappropriate transmission levels.

** Of the 48 respondents who sometimes ride in darkenss, 7 had visors of inappropriate transmission levels

5.4.2 Transport Research Laboratory survey

The results of the Transport Research Laboratory survey are given in Appendix 3. These results compare favourably with those found from the survey of motorcyclists views reported above.

5.4.3 South Yorkshire Police

Raw data from surveys undertaken by South Yorkshire police in which visors being used on the road were measured using ‘Tintman’ are given below. The table shows that illegal visors, in terms of their luminous transmission values, can be obtained and used on the roads.

Table 17: Luminous transmission values for South Yorkshire police visor surveys

Manufacturer	*Comment*	**Grade**	**Tintman reading %** **(taken at visor centre)**
AGV		Smoke	21.3
Arai		Clear	88.0
Arai		Dark	21.3
Arai		Iridium	16.7
Arai	Kite mark	Smoke	57.0
BMW System4	Daytime use	Dark	15.0
Bob Heath	Daytime use	Smoke	50.0
Nolan Xlite	No marks	Dark	14.5
Nolan Xlite		Iridium	30.1
Roof	Boxer	Dark	16.2
Roof	Roadster	Dark	19.2
Shark		Dark	13.1
Shoei CX1		Dark	20.0
Shoei CX1		Iridium	28.0
Shoei CX1		Yellow	46.2
Shoei CX1		Smoke	57.0
Suomy	Fitted with clear fog visor	Dark	13.5
Suomy		Iridium	11.4

5.5 Summary of visor usage surveys

The data obtained from the visor usage surveys by both ICE Ergonomics and south Yorkshire police indicate that illegal visors can be obtained for use on the road. In addition ICE's work further indicates that illegal visors (those with a luminous transmission of less than 50%) and those for daytime use only (those with a luminous transmission between 50-80%) will be used inappropriately in conditions of reduced ambient lighting.

6.0 Luminous transmission trials

The aim of these trials was to investigate the relationship between the level of luminous transmission and the ability to detect objects in the road under conditions of:

- bright daylight,
- bright daylight with target objects in shadow,
- cloudy/overcast day,
- low sun,
- dawn/dusk/twilight,
- night-time with streetlights (dry),
- night-time with streetlights (wet),
- night-time without streetlights.

This was undertaken with a view to optimise driver/rider performance for each condition and across all conditions.

In order to investigate the effect of decreasing luminous transmission (darker tints), on drivers'/riders' ability to detect target objects in a road scene, a series of trials were conducted on the model road facility at ICE Ergonomics and these are described below.

6.1 The model road

The model road consists of a light proof box 8m long by 1.25m wide with a 1:20 scale road modelled inside. The road's surface reflectivity characteristics and macro texture are modelled on black asphalt (Q_o 0.07). The top surface of the box has seven apertures over which streetlights are placed to allow light to fall onto the road's surface in a manner representative of night-time streetlighting. Adjusting the size of the aperture controls the level of illumination, whilst polished aluminium baffles are used to control the uniformity of the light. Through combinations of different lighting, a range of daytime lighting conditions can also be simulated.

The model road scene is viewed through a shutter mechanism that can be adjusted to give the observer varying glimpse durations of the road scene. Exposure times of 200 milliseconds are typically used for experiments investigating static, small target visibility because they represent a realistically arduous condition in visual search and detection behaviour. Whilst scanning a scene, rapid saccadic eye movements result in changes of fixation which are typically 200 milliseconds in duration. Each fixation brings the retinal image of an object being viewed onto the fovea where there is high spatial resolution.

The observer's viewing position in the model is equivalent to 1.5m above the road's surface and gives a realistic drivers' eye view of the scene. Refer to Figures 1and 2.

Figure 1: Observers view of model road

Figure 2: Model road facility

(The side of the model is shown removed for the purposes of the photograph)

6.2 Test Variables

6.2.1 Target Objects

The target objects presented in the road scene were a 1:20 scale adult male pedestrian of 95th %ile height and a scaled 20cm flat disc, each with a uniform 20% reflectivity.

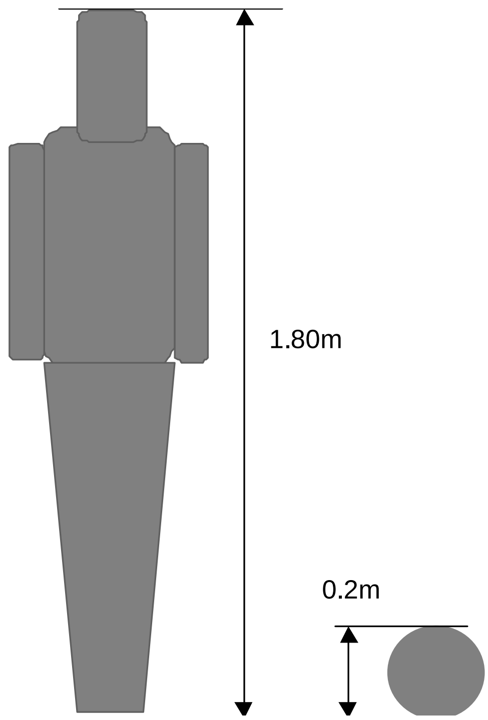


Figure 3: Target objects6.2.2 Test Materials

Targets were viewed through materials with different luminous transmission properties. A description of each material, its luminous transmission and the rationale for selection are shown in Table 18.

Table 18: Test material's description and specification

Material	L.T.	Rationale
Laminated glass windscreen - with clear interlayer	82%	Windscreens must have a luminous transmittance > 75% (ECE Reg. No. 43) and motorcycle crash helmet visors >80% (ECE Reg. No. 22.05 and BS6658)
Toughened glass side window -	74.5%	Automotive glazing, other than windscreens must have luminous transmittance >70% (ECE Reg. No. 43)
Lexon coated thin gauge polycarbonate motor cycle crash helmet visor	51%	Motorcycle crash helmet visors may have a luminous transmittance ≥50% if marked "Daytime use only" (ECE Reg. No. 22.05 and BS6658)
Toughened glass side window (Pilkington Optikool) with a *light smoke* tint film applied.	45.3%	Goggles with filter category 12 or sunglasses with filter category 1 (light tint) shall have luminous transmittance >43% - defined 'suitable for driving' by BS EN 1938 and 1836 respectively
Toughened glass side window (Pilkington Optikool) with a *smoke bronze* tint film applied.	33.4%	Many worldwide regulatory authorities accept down to 35% luminous transmission for side and rear windows. These include South Africa, some states in USA and Australia.
Toughened glass side window (Pilkington Optikool) with a *midnight* tint film applied.	19.6%	Most members of the BS visor committee support a reduction in the minimum light transmission of visors to ≥18%. Some research evidence was found which was also supportive of this. Refer to section 2.1.3 It appears from the research and standards that the minimum light transmission which should be considered for drivers and riders is 18%, although this seems to be in conflict with BSEN1836 (sunglasses – see section 2.1.3).

6.2.3 Ambient Light Levels

Eight ambient lighting conditions were replicated in the model road. These are described in Table 19.

Table 19: Model road ambient lighting conditions

<table>
<tr><th>Lighting Condition</th><th>Max & Mean Luminance in the vicinity of the target (cd/m2)</th></tr>
<tr><td>Bright daylight</td><td>4661 442</td></tr>
<tr><td colspan="2">The bright daylight condition is that under which motorcyclists wish to be granted permission to wear eye protection with luminous transmission properties as low as 18%.</td></tr>
<tr><td>Bright daylight with target objects in shadow</td><td>1400 392</td></tr>
<tr><td colspan="2">This lighting condition may be encountered in a road scenario where a driver/rider, whose eyes are adapted to bright daylight conditions, is approaching an area of road in dark shadow.</td></tr>
<tr><td>Cloudy/Overcast day</td><td>1143 226</td></tr>
<tr><td colspan="2">A lighting condition which could be encountered by a motorcyclist or driver who began a journey in bright daylight.</td></tr>
<tr><td>Low sun (high luminance glare source in drivers'/riders' field of vision).</td><td>90600 3017</td></tr>
<tr><td colspan="2">Another lighting condition where motorcyclists wish to use eye protection with low luminous transmission.</td></tr>
<tr><td>Dawn/Dusk/Twilight</td><td>7.48 1.34</td></tr>
<tr><td colspan="2">A lighting condition which is likely to be encountered by a motorcyclist or driver who began a long journey in bright daylight.</td></tr>
<tr><td>Night time with street lights and headlamps on - dry road.</td><td>6.47 0.98</td></tr>
<tr><td colspan="2">A lighting condition under which heavily tinted visors and windscreens may be misused.</td></tr>
<tr><td>Night time with street lights and headlamps on - wet road.</td><td>3.53 0.82</td></tr>
<tr><td colspan="2">A lighting condition under which heavily tinted visors and windscreens may be misused.</td></tr>
<tr><td>Night time, unlit road, headlamps on.</td><td>0.64 0.11</td></tr>
<tr><td colspan="2">A lighting condition under which heavily tinted visors and windscreens may be misused.</td></tr>
</table>

6.2.4 Trial Participants

Twenty, current UK driving licence holding participants (7 male and 13 female) whose ages ranged from 18 to 75 years (mean age 44 years, SD 16.3) were recruited from ICE's database.

6.3 Test methodology

For each ambient lighting condition, each subject viewed the road scene through each test material for a duration of 200ms. Pedestrian or disc targets were presented at one of six positions in the road scene corresponding to left kerb, right kerb or road centre at 23m or 73m distance from the participant. These distances equate to an approximate stopping distance i.e. thinking and braking distance, for a vehicle travelling at 30mph and 60mph respectively. Pre-trial testing indicated that it was only necessary to assess the pedestrian target at 73m since it could be consistently accurately detected at 23m. The participants were required to indicate whether a target was present in the road scene and in order to detect a participant’s willingness to guess at a target's presence, for each condition 50% of the road scene exposures had no target present.

6.4 Bright daylight

6.4.1 Methodology

Under the 'bright day' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Pre-trial testing indicated that it was not necessary to assess the pedestrian target in this condition since it could be consistently accurately detected at 73m.

6.4.2 Results/Findings

Figure 4 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under bright ambient lighting conditions.

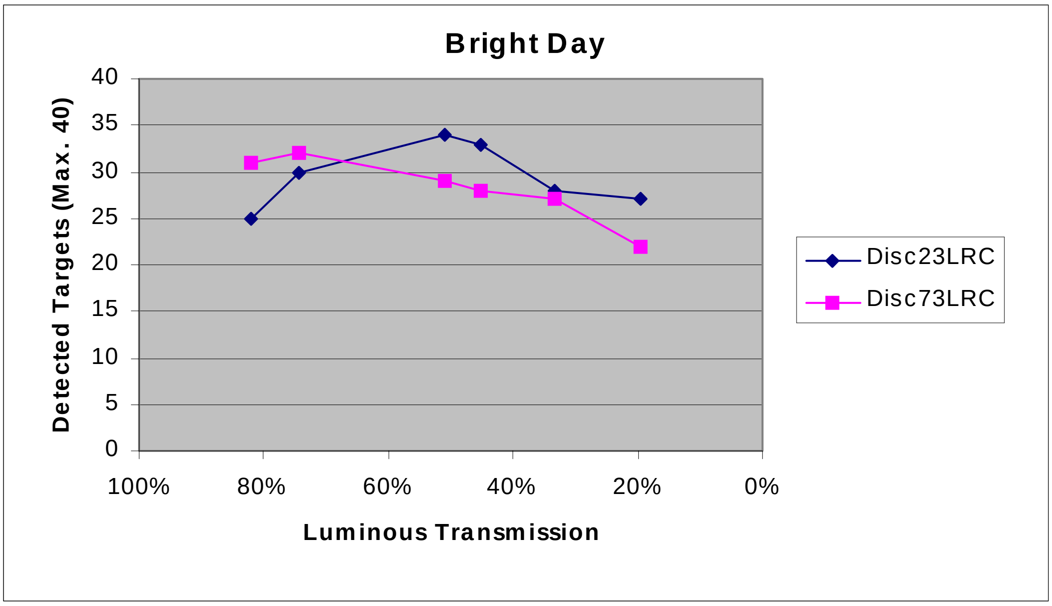


Figure 4: Target detection under bright, daytime conditions

6.4.3 Conclusions

Although the graph appears to indicate that disc targets at 23m are easier to see when viewed through materials with luminous transmission of approximately 50% and disc targets at 73m are more difficult to see as luminous transmission reduces, these are not statistically significant.[1] The trends seen are due to random variation and luminous transmission does not affect target detection under bright daylight conditions.

[1] All data was tested for statistical significance using a two-tailed, paired t-test at 5% significance. Any apparent differences between conditions which are not significant are due to natural variability in the data and are not due to transmission level.

6.5 Bright daylight with target objects in shadow

6.5.1 Methodology

Under the 'bright daylight with target in shadow' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb.

Additionally, a pedestrian target was presented twice at the 73m distance, one presentation at the road centre position the other at either left kerb or right kerb.

6.5.2 Results/Findings

Figure 5 illustrates the effect of a material's luminous transmission on subjects' ability to detect disc targets at 23m and 73m and pedestrian targets at 73m under bright ambient lighting conditions with the target objects in shadow.

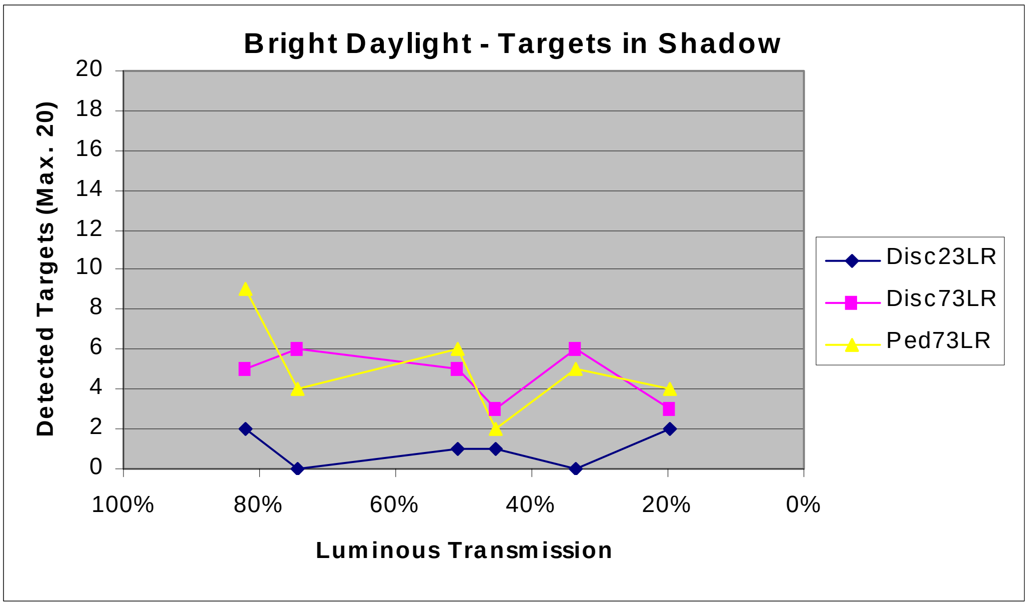


Figure 5: Target detection under bright, daytime conditions with targets in shadow

The maximum target detections for this condition are 20 since only the off-centre targets represented the worst case scenario for this condition of low contrast between the target and its background as well as high levels of ambient illumination.

6.5.3 Conclusions

Figure 5 shows that, as a proportion, the number of targets detected has reduced compared to the previous condition of bright daylight. This is to be expected since the low contrast of the target against its background, caused by the effects of shadows, increases the difficulty of the detection task.

Statistical analysis indicates that there is no significant difference across the different levels of luminous transmission for all of the targets i.e. the peaks and troughs shown in figure 5 are due to random variation and luminous transmission does not affect detection.

In addition there is no statistical difference between the targets across the different levels of luminous transmission i.e. the disc at 23m is not more difficult to detect than the disc or pedestrian at 73m.

6.6 Cloudy, overcast day

6.6.1 Methodology

Under the 'cloudy, overcast day' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Pre-trial testing indicated that it was not necessary to assess the pedestrian target since it could be consistently accurately detected at 73m.

6.6.2 Results/Findings

Figure 6 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under cloudy overcast lighting conditions.

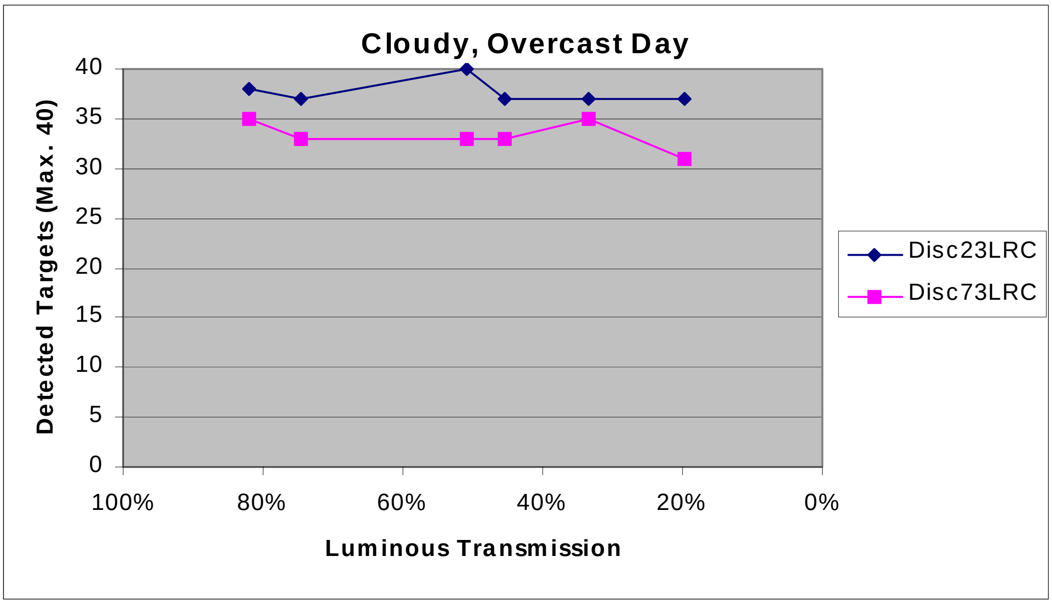


Figure 6: Target detection under cloudy, overcast conditions

6.6.3 Conclusions

This condition suggests an improvement in the detection rates for discs at both 23m and 73m over previous conditions although this is not statistically significant over the whole data range. The greater contrast of the targets against their background compared to condition 2 (bright day with targets in shadow) facilitates their detection whilst the reduction in ambient lighting compared to condition 1 (bright daylight) also assists detection.

Statistical analysis indicates that for disc targets at both distances there is no significant difference in their detection rates across the different levels of luminous transmission. The graph above therefore depicts random variation and luminous transmission does not affect target detection.

1.1. 6.7 Low sun condition

6.7.1 Methodology

Under the 'low sun' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Additionally, a pedestrian target was presented twice at the 73m distance, one presentation at the road centre position the other at either left kerb or right kerb.

6.7.2 Results/Findings

Figure 7 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under low sun ambient lighting conditions.

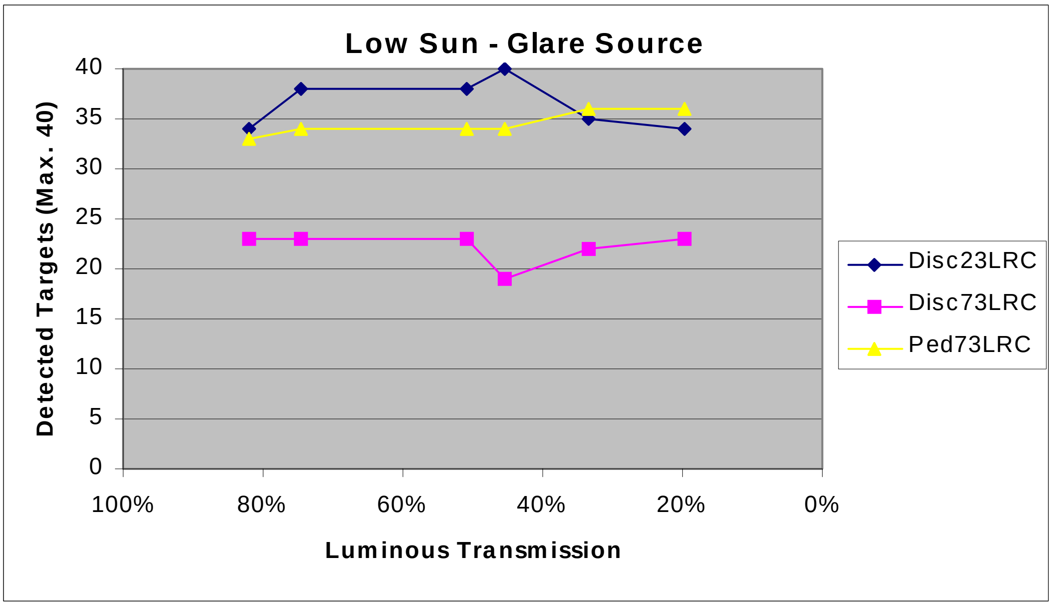


Figure 7: Target detection under cloudy, overcast conditions

6.7.3 Conclusions

Statistical analysis indicates that there is no significant difference across the different levels of luminous transmission for all of the targets i.e. the peaks and troughs shown in Figure 7 are not significant and luminous transmission does not affect detection.

Comparing the data in Figure 7 with that in Figure 6, it can be seen that sun glare reduces the visibility of the small disc target at the longer viewing distance of 73m. However Figure 7 shows that tinting does not assist with this problem.

6.8 Dawn/Dusk conditions

6.8.1 Methodology

Under the 'dawn/dusk' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Additionally, a pedestrian target was presented twice at the 73m distance, one presentation at the road centre position the other at either left kerb or right kerb.

6.8.2 Results/Findings

Figure 8 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under 'dawn/dusk' ambient lighting conditions.

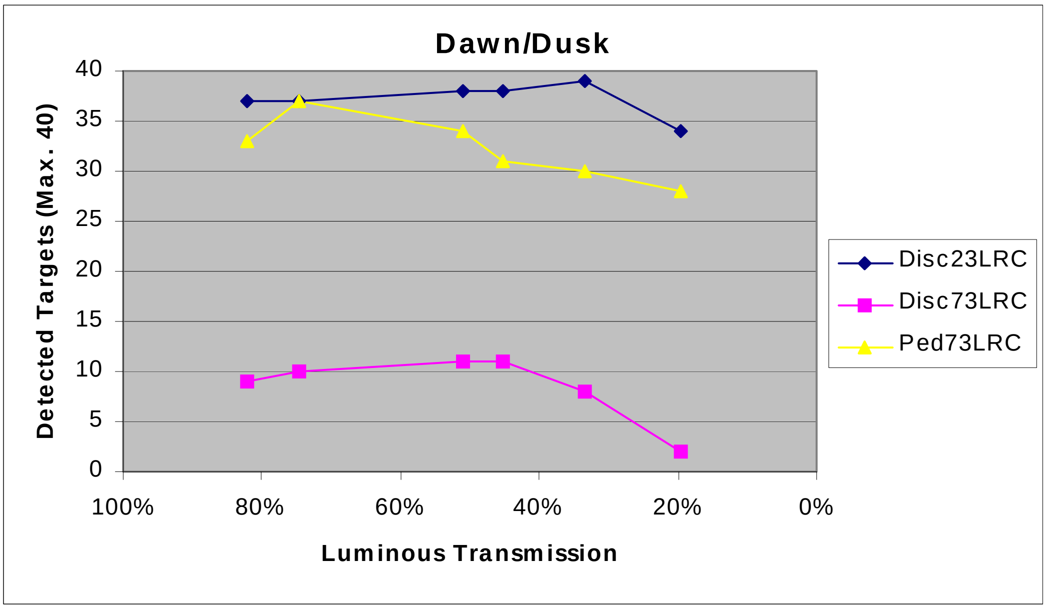


Figure 8: Target detection under dawn/dusk conditions

6.8.3 Conclusions

With respect to the disc targets at both 23m and 73m, there was no statistically significant difference in their detection rates across the different levels of luminous transmission i.e. luminous transmission did not affect target detection. However analysis of the pedestrian data indicated a significant decrease in pedestrian detections between luminous transmissions of 74.5% and 19.6%. No significant effects were observed between other levels of luminous transmission. It may appear curious that luminous transmission appears only to affect the larger pedestrian target and not the smaller disc target when viewed at 73m. An explanation for this is that the smaller disc target is too small to be clearly seen and detection rates are only likely to be significantly improved by increasing the ambient illumination. The pedestrian target is sufficiently large to have improved detection rates over the disc but these are eroded by the reduced contrast of the pedestrian with its background when viewed through materials with reduced luminous transmission. Hence as luminous transmission reduces, the rate of pedestrian detection falls as shown by the graph.

The reduced detection rate for disc targets at 73m across all levels of luminous transmission is statistically significant compared to the disc target at 23m and pedestrian target at 73m.

6.9 Night time with street lights and headlamps - dry road.

6.9.1 Methodology

Under the 'night time with street lights and headlamps - dry road' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Additionally, a pedestrian target was presented twice at the 73m distance, one presentation at the road centre position the other at either left kerb or right kerb.

6.9.2 Results/Findings

Figure 9 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under 'night time with street lights and headlamps - dry road' ambient lighting conditions.

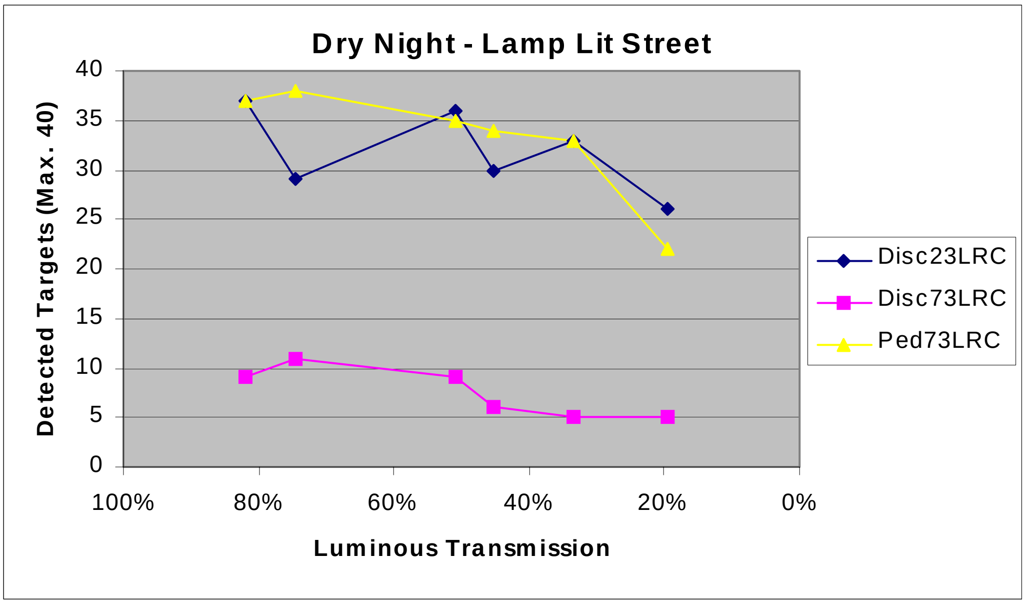


Figure 9: Target detection under dry, night-time conditions with street lights and headlamps

6.9.3 Conclusions

With respect to the disc targets at both 23m and 73m, there was no statistically significant difference in their detection rates across the different levels of luminous transmission i.e. luminous transmission did not affect target detection. However analysis of the pedestrian data indicated a significant decrease in pedestrian detections between luminous transmissions of 74.5% and 19.6%. The rationale for the larger pedestrian target being affected by reducing levels of luminous transmission and not the smaller disc target when both are viewed at 73m is given in section 6.8.3.

The reduced detection rate for disc targets at 73m across all levels of luminous transmission is statistically significant compared to the disc target at 23m and pedestrian target at 73m.

6.10 Night time with street lights and headlamps - wet road

6.10.1 Methodology

Under the 'night time with street lights and headlamps - wet road' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Additionally, a pedestrian target was presented twice at the 73m distance, one presentation at the road centre position the other at either left kerb or right kerb.

6.10.2 Results/Findings

Figure 10 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under 'night time with street lights and headlamps - wet road' ambient lighting conditions.

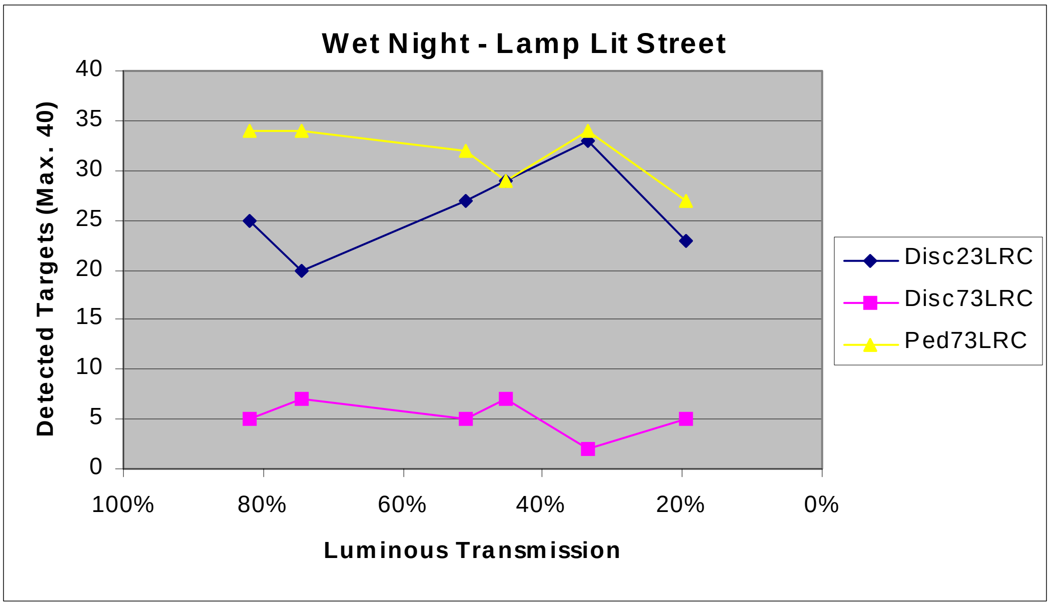


Figure 10: Target detection under wet, night-time conditions with street lights and headlamps

6.10.3 Conclusions

With respect to the disc at 73m and the pedestrian at 73m there was no statistically significant difference in the detection of these targets across the various levels of luminous transmission i.e. luminous transmission did not affect detection.

Significant differences found for the disc target at 23m with respect to the material with 33.4% luminous transmission were further investigated and were found to be due to procedural issues in the experimental design rather than a true result. Analysis of the raw data suggested that disc targets at 23m were likely to be seen more easily under this particular test condition, whilst the same targets viewed under the material of 74.5% luminous transmission were likely to have been more difficult to see. If allowances were made to compensate for this the graphical line for disc target at 23m shown in Figure 10 would become flatter suggesting that luminous transmission is less likely to have an effect on detection.

The reduced detection rate for disc targets at 73m across all levels of luminous transmission is statistically significant compared to the disc target at 23m and pedestrian target at 73m.

6.11 Night time with headlamps only- dry road.

6.11.1 Methodology

Under the 'night time with headlamps only - dry road' ambient lighting condition, each subject was presented with a disc target twice at each distance - 23m and 73m - and viewed through each of the test materials. One disc presentation was at the road centre position the other was either left kerb or right kerb. Additionally, a pedestrian target was presented twice at the 73m distance, one presentation at the road centre position the other at either left kerb or right kerb.

6.11.2 Results/Findings

Figure 11 illustrates the effect of a material's luminous transmission on subjects' ability to detect centre and off-centre disc targets at 23m and 73m under 'night time with headlamps only - dry road' ambient lighting conditions.

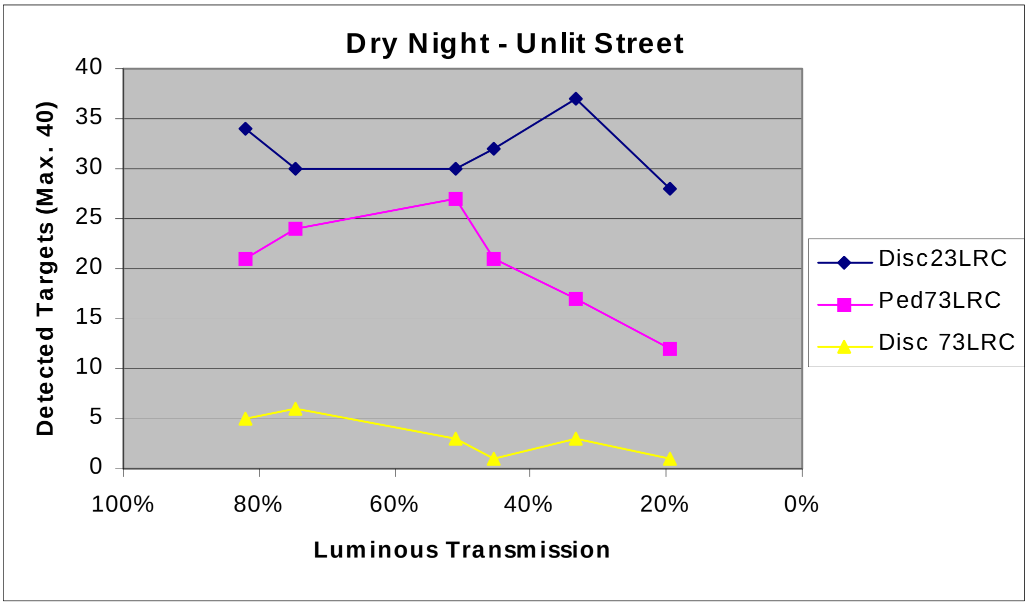


Figure 11: Target detection under dry, night-time conditions with headlamps only

6.11.3 Conclusions

With respect to the discs at 23m and 73m, there was no statistically significant difference in the detection of these targets across the various levels of luminous transmission i.e. luminous transmission did not affect detection and the peaks and troughs shown are not significant.

A significant difference was found for the pedestrian target at 73m when viewed through a material with a luminous transmission of 51% compared to one of 19.6%. It is likely that this is a feature of the experimental design rather than a true result and the real detection rate is likely to be somewhat lower than that shown. Analysis of the downward sloping curve for luminous transmission levels

74.5%, 45.3%, 33.4% and 19.6% indicates that for every 5% reduction in transmission, approximately one additional pedestrian would not be detected.

The reduced detection rate for disc targets at 73m across all levels of luminous transmission is statistically significant compared to the disc target at 23m and pedestrian target at 73m.

6.12 Summary

Luminous transmission did not affect the probability of detection of the disc targets at 23m or 73m. Instead the probability of detecting a disc target appears to be more dependent upon the level of ambient lighting. This is indicated by the finding that the disc target at 73m was significantly more difficult to see i.e. had fewer correct detections than the other targets, under the low sun condition and the dawn/dusk and night-time conditions. Under these conditions the detection rate of the disc at 73m was consistently low across all the levels of luminous transmission. This suggests that the smaller disc target was too small to be clearly seen and detection rates are only likely to be significantly improved by increasing the ambient illumination.

The pedestrian target at 73m was significantly more difficult to see under the dawn/dusk and dry, night-time with streetlighting condition when viewed through the materials with 19.6% luminous transmission compared to one with 74.5%. No significant effects were observed between other levels of luminous transmission. Since there was found to be no significant difference in detection between 75% and 33.4% and some significant difference in detection between 75% and 19.6%, the question arises as to what point, between these two levels does the detection of pedestrians just become significant i.e. the threshold between acceptable and unacceptable pedestrian detection rates.

To make this estimate it was necessary to create ‘dummy’ target detection data for incremental levels of transmission between 33.4% and 19.6%. The data columns would total to the required number of pedestrians detected. Statistical tests could then be made comparing this theoretical data against the actual data. The number of pedestrians detected, which just reached significance, could then be related to the known data to find the corresponding transmission level.

Care was taken in the creation of the ‘dummy’ date to ensure that the range of responses was similar to the actual data so that variances would be similar.

The tables below shown the actual and dummy data and will help the reader comprehend the methodology (see particularly the night-time with streetlights and headlamps condition).

Dawn/dusk condition

Table 20: Significance calculations for dawn/dusk condition

Ped 73	82	74.5	51	45.3	33.4	19.6		dummy data
Transmissi	A	B	C	D	E	F		x1
Subject 1	0	0	0	0	0	0		0
Subject 2	2	2	2	1	1	1		1
Subject 3	1	2	2	2	2	1		2
Subject 4	1	1	1	2	0	1		1
Subject 5	2	2	2	2	2	1		1
Subject 6	2	2	2	1	1	1		1
Subject 7	2	2	2	1	1	2		2
Subject 8	2	2	2	2	2	2		2
Subject 9	2	2	1	2	2	1		1
Subject 10	2	2	2	1	1	2		2
Subject 11	2	2	2	2	2	2		2
Subject 12	2	2	2	2	2	2		2
Subject 13	1	2	2	1	2	2		2
Subject 14	2	2	2	2	2	2		2
Subject 15	1	2	1	2	2	1		1
Subject 16	2	2	2	2	2	2		2
Subject 17	2	2	2	2	1	2		2
Subject 18	2	2	2	2	1	1		1
Subject 19	1	2	2	2	2	1		1
Subject 20	2	2	1	0	2	1		1
Total Cond	33	37	34	31	30	28	0	29

Condition 2	A	B	C	D	E	F		
A		0.042086	0.666264	0.577032	0.379263	0.056337	82	0.16255
B			0.082814	0.055257	0.004729	0.000873		0.002095
C				0.329877	0.214111	0.010163		0.020992
D					0.771534	0.379263		
E						0.540884		
F								

t.05(19)=+/-2.093
2 tailed, paired comparison
Bonferroni 0.003333

Hence reduced visual performance would reach statistical significance when 29 or fewer pedestrians were detected.

To convert this to a transmission level we interpolate between the performance at 33.4 % transmission (30 pedestrians detected) and the 19.6% transmission (28 pedestrians detected)

Significant transmission would therefore occur mid way between 19.6% and 33.4% i.e. **26.5%**

6.12.1 Night-time with streetlighting and headlamps – dry road

Table 21: Significance calculations for night-time with streetlighting and headlamps - dry road

Ped 73	82	74.5	51	45.3	33.4	19.6		dummy data			
Transmissi	A	B	C	D	E	F		x1	x2	x3	x4
Subject 1	2	2	2	2	2	0		0	0	0	1
Subject 2	2	2	2	2	2	0		2	2	2	2
Subject 3	2	2	2	2	1	1		1	1	2	1
Subject 4	1	2	1	1	1	0		0	1	0	0
Subject 5	2	2	2	2	2	2		2	2	2	2
Subject 6	2	1	2	1	1	0		0	0	1	2
Subject 7	2	2	1	1	1	2		2	2	2	2
Subject 8	2	2	2	2	2	2		2	2	2	2
Subject 9	1	2	2	1	2	1		1	1	1	2
Subject 10	2	2	1	2	2	1		1	1	1	1
Subject 11	2	2	2	2	2	2		2	2	2	2
Subject 12	2	2	2	2	2	2		2	2	2	2
Subject 13	1	1	2	2	1	2		2	2	2	2
Subject 14	2	2	1	2	2	2		2	2	2	2
Subject 15	2	2	2	2	2	0		0	0	0	1
Subject 16	2	2	2	2	1	1		1	1	1	1
Subject 17	2	2	2	2	2	1		1	2	1	1
Subject 18	2	2	1	1	1	0		0	0	2	0
Subject 19	2	2	2	2	2	1		1	1	1	2
Subject 20	2	2	2	1	2	2		2	2	2	2
Total Cond	37	38	35	34	33	22	0	24	26	28	30

Condition 2	A	B	C	D	E	F					
A		0.577032	0.42829	0.186411	0.103603	0.001576	82	0.003585	0.012118	0.01577	0.04926
B			0.267433	0.103603	0.020992	0.000766	74.5	0.001819	0.004036	0.014089	0.042086
C				0.666264	0.42829	0.005706	51	0.012118	0.035127	0.089626	0.09615
D					0.666264	0.006733					
E						0.012118					
F											

t.05(19)=+/-2.093
2 tailed, paired comparison
Bonferroni 0.003333

Hence reduced visual performance would reach statistical significance when 24 or fewer pedestrians were detected.

To convert this to a transmission level we interpolate between the performance at 33.4 % transmission (33 pedestrians detected) and the 19.6% transmission (22 pedestrians detected).

Hence significant transmission = 19.6 + 0.18(33.4-19.6) = **23.16%**

6.12.2 Night-time with streetlights and headlamps – wet road

Even the lowest level of transmission did not show a reduction in pedestrian detection rate.

6.12.3 Night-time with headlamps only – dry road

Table 22: Significance calculations for night-time with headlamps only - dry road

Ped 73	82	74.5	51	45.3	33.4	19.6		dummy data			
Transmissi	A	B	C	D	E	F		x1	x2	x3	x4
Subject 1	1	2	2	0	1	1		1	1	1	1
Subject 2	2	1	2	2	2	1		1	1	1	1
Subject 3	2	1	2	2	0	0		1	0	1	0
Subject 4	1	0	1	2	1	1		2	1	0	1
Subject 5	0	2	1	1	0	0		1	1	1	1
Subject 6	1	0	2	0	0	1		0	1	0	1
Subject 7	0	1	0	0	0	0		1	1	1	1
Subject 8	2	2	2	1	0	1		2	1	2	1
Subject 9	1	1	1	1	1	1		1	1	1	1
Subject 10	1	2	2	1	1	1		1	2	1	2
Subject 11	0	2	1	1	1	0		2	0	2	0
Subject 12	2	0	1	0	0	0		1	1	1	1
Subject 13	2	2	2	1	0	1		0	0	0	0
Subject 14	0	1	2	1	1	1		0	2	0	0
Subject 15	1	0	1	1	0	0		1	1	1	1
Subject 16	0	2	0	2	2	1		1	0	1	0
Subject 17	2	1	2	1	1	0		0	1	0	1
Subject 18	0	1	0	1	2	0		0	0	0	0
Subject 19	2	1	1	1	2	1		0	0	0	0
Subject 20	1	2	2	2	2	1		0	0	0	0
Total Cond	21	24	27	21	17	12	0	16	15	14	13

Condition 2	A	B	C	D	E	F					
A		0.590583	0.082814	1	0.479393	0.035127	82	0.329877	0.229644	0.167047	0.07239
B			0.505382	0.481035	0.12967	0.004036	74.5	0.088031	0.082814	0.014089	0.030201
C				0.186411	0.076138	0.000162	51	0.037392	0.004036	0.011546	0.001819
D					0.258452	0.01577					
E						0.171317					
F											

t.05(19)=+/-2.093
2 tailed, paired comparison
Bonferroni 0.003333

Hence reduced visual performance would reach statistical significance when 13 or fewer pedestrians were detected.

To convert this to a transmission level we interpolate between the performance at 33.4 % transmission (17 pedestrians detected) and the 19.6% transmission (12 pedestrians detected)

Significant transmission = 19.6 + 0.2(33.4-19.6) = **22.36%**

6.12.4 Potential comfort benefits of tinted visors at night

A theoretical assessment of the potential comfort benefits of tinted visors can be made by calculating the effects on the reduction in the transmission of light from oncoming vehicle headlamps. From this it is possible a make a prediction of the effect on the comfort sensation.

A model for predicting the comfort effects of a glare source was developed by Alferdinck (1996) and used to predict the discomfort glare sensation produced by vehicle headlamps. This model was the result of a series of experiments examining the effect of headlamp size on subjective ratings of glare. Alferdinck derived an equation which describes the discomfort glare **D** as a function of glare source area **A** (deg^2), glare illuminance $\mathbf{E_G}$ (lux) and glare angle $\boldsymbol{\theta}$ (^{o}).

$$\mathbf{D\ (E_G.\ A.\ \theta\ ) = 3.15-2.19\ \log(E_G) + 1.138\ \log(\theta) + 0.298\ \log(A) - 0.242\ \log(\theta)\ \log(A)}$$

The output from this equation is a rating of discomfort analogous to de Boer's scale. For vehicle headlamps the values generated are within the range 1 to 9 with high ratings implying low discomfort. The scale descriptors used by de Boer are used (see below for de Boer's scale).

1 Unbearable
2
3 Disturbing
4
5 Just acceptable
6
7 Satisfactory
8
9 Just noticeable

For current purposes we have taken the illuminance of an the oncoming car headlamp as measured at point B50R in the beam pattern, which relates to the eye position of an oncoming driver (referred to as the 'glare point').

The table below shows that this would give a discomfort rating of 4.5 when viewed directly.

Table 23

Point	Glare illuminance (lux)	glare angle	glare area (deg.sq)	discomfort glare
B50R	0.4	3	0.413	4.5

By applying Alferdick's model and taking into account the effects of the reduction in illuminance under the different visor/windscreen transmission levels the effects on comfort have been estimated in the table below: -

Table 24

Transmission %	Discomfort rating
82	4.7
74.5	4.8
51	5.1
45.3	5.2
33.4	5.5
19.6	6.0

This suggests that there is an objective comfort benefit to be derived from the use of higher tints at night, and may move the sensation from being just unacceptable to acceptable. This of course should be verified with user trials.

6.13 Conclusions/recommendations

This work has not found there to be a significant reduction in the ability to detect pedestrians at night until visor/windscreen transmissions fall below around 27%. (Dawn/dusk = 26.5%, Dry Night, lamp lit street = 23.16%, Dry night, until street = 22.36%, Wet night – lamp lit street = no effect on detection of any of the levels tested).

Estimates, based on mathematical models, indicate that visors or windscreens with such transmission levels will improve comfort during night-time driving/riding.

It is important to note that these findings are based on theoretical calculations, which were in turn based on laboratory tests. Considering the potential safety implications, it is strongly advised that these findings and any recommendations based on them are validated by further objective and, potentially, real-world trials.

Research by Rompe and Engel (in Taylor undated) indicates that spectacle wearers have more difficulty detecting low contrast targets in low ambient lighting conditions through tinted materials. Age was also found to have a similar effect (Allen et al 1996 and the AA). It should therefore be ensured that these categories of drivers are represented within the validation trials in sufficient number to enable analysis of the contribution of these factors.

7.0Windscreen inclination - Installed luminous transmission

An additional factor that will decrease luminous transmission of a vehicle's glazing is its angle of inclination relative to the driver's line of sight. Most national standards relating to vehicle windscreens specify minimum limits of luminous transmittance, but only when measured at normal incidence. As installed inclination increases, luminous transmittance losses due to reflections at the surfaces and absorption within the bulk of the material also increase.

In a recent study, conducted by ICE Ergonomics (Quigley et al 2000), 27 cars between 0 and 3 years old were surveyed. Installed windscreen inclinations were found to range between 41º to 63º from vertical with an average of 59º. Typically, the decrease in luminous transmission over this range is approximately 10%. Refer to Figures 25 and 26 below. To make allowances for windscreen inclination, it would be prudent to increase the luminous transmission levels used in ICE’s work (which were based on measures of luminous transmission made perpendicular to the material) by up to 10% in order to be representative of on-the-road conditions. This adjustment does not affect our recommendation made in the previous section when applied to motorcycle visors. Motorcycle visors are likely to have angles up to 30° (Wigan 1979) which Figures 12 and 13 indicate have minimal effects on installed light transmission.

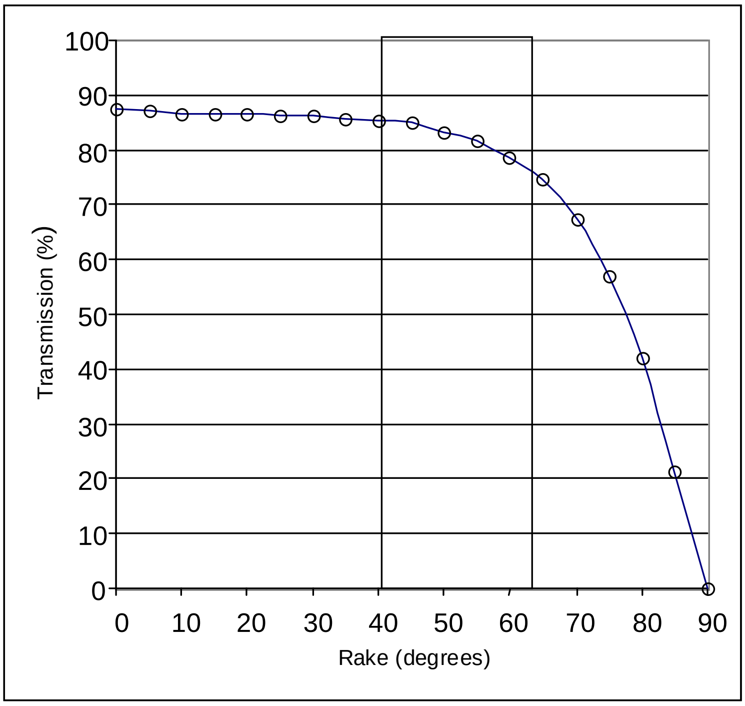


Figure 12: Installed light transmission (from Smith, G. and Bryant, J.F.M., The optical properties of tilted windscreens under practical conditions)

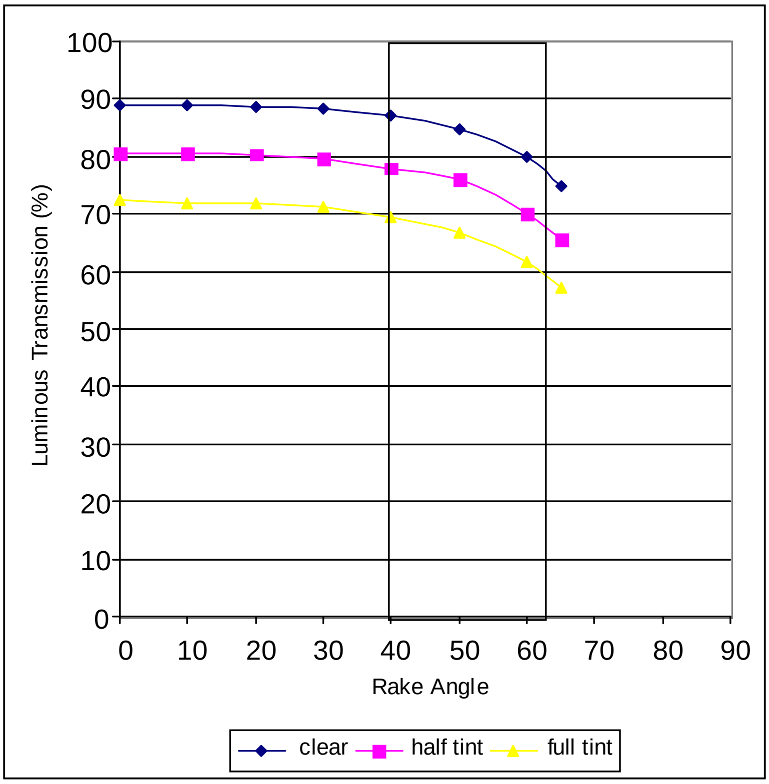


Figure 13: Luminous transmission (from Hills, B.L., Transmittance measurements on windscreens and test samples: The effects of rake angle)

8.0 Windscreen abrasion trials

Long-term exposure to the elements and prolonged usage of windscreen wipers causes the outer surface of a windscreen to become pitted and abraded. This surface damage causes light to be scattered as it passes through the windscreen. The resultant veiling glare can cause areas of the road scene to be obscured to the driver. When an on-coming light source, such as a headlamp beam, passes through a clean, undamaged windscreen the glare will be disabling but localised at the sources centre. Abrasion on a windscreen’s surface causes an increasing area and luminance of veiling glare around the headlamp's centre.

8.1 Methodology

As a means to discover the correlation between abrasion on a windscreen's surface and the resultant luminance of the veiling glare, twenty-four windscreens were obtained from a windscreen replacement company. Each of the windscreens was an original, factory-fitted item so that a vehicle’s mileage, recorded at the time of replacement, might accurately indicate exposure duration. The exposure mileage for each of the windscreens tested is shown below in Figure 14.

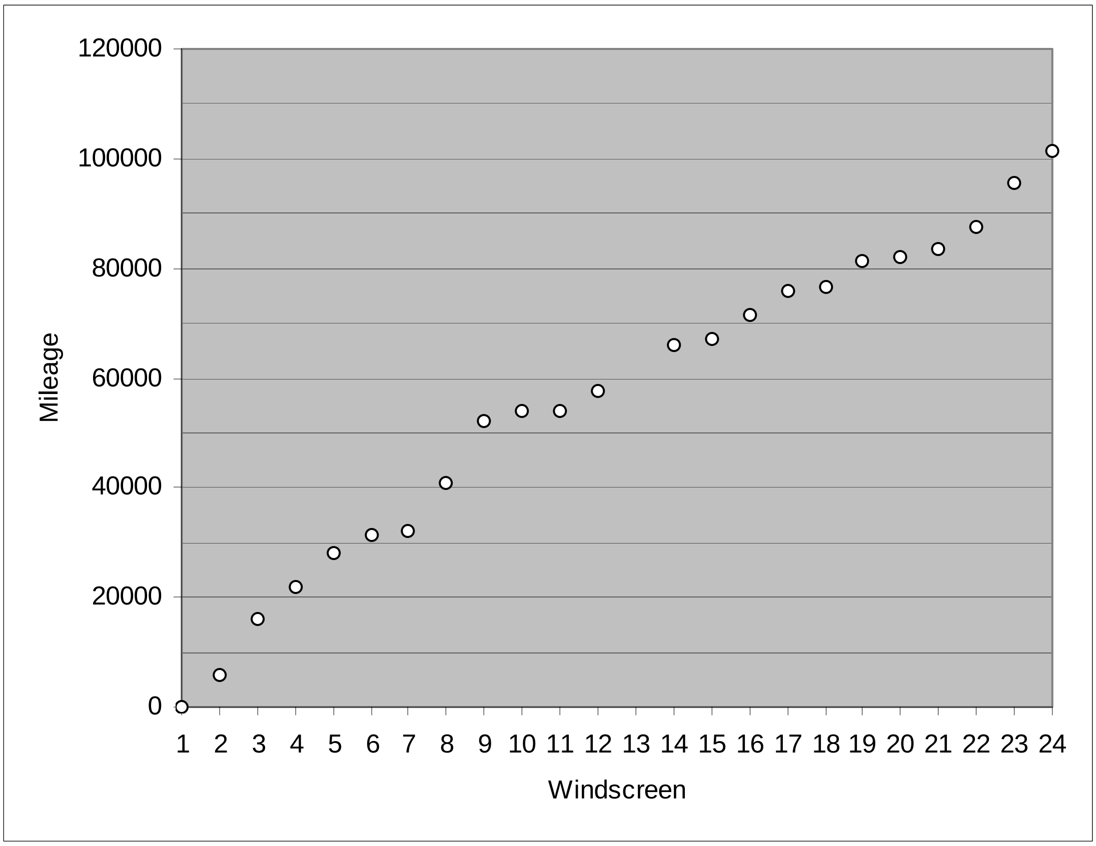


Figure 14: Exposure mileage for windscreen sample

8.1.1 Test apparatus

To measure the luminance of the veiling glare, created by a light source passing through an abraded windscreen, a test methodology was developed that utilised a digital, photometric image analysis system. The IQ-Cam system consists of a photometrically calibrated, digital, still frame camera connected to a host computer. Images captured by the camera are converted to a digital form so that the IQ-Cam software can perform photometric scene analysis and report measurements.

The test apparatus consisted of a tungsten filament lamp positioned at the end of a parallel-sided tube that was directed towards the IQ-Cam lens through a test windscreen. To prevent over exposure of the image at the lamp's centre, a solid disc the same diameter as the tube was placed on the windscreen directly between the light source and the camera. So that measurements were taken under consistent ambient lighting conditions the apparatus were housed in a light proof box. Refer to Figure 15.

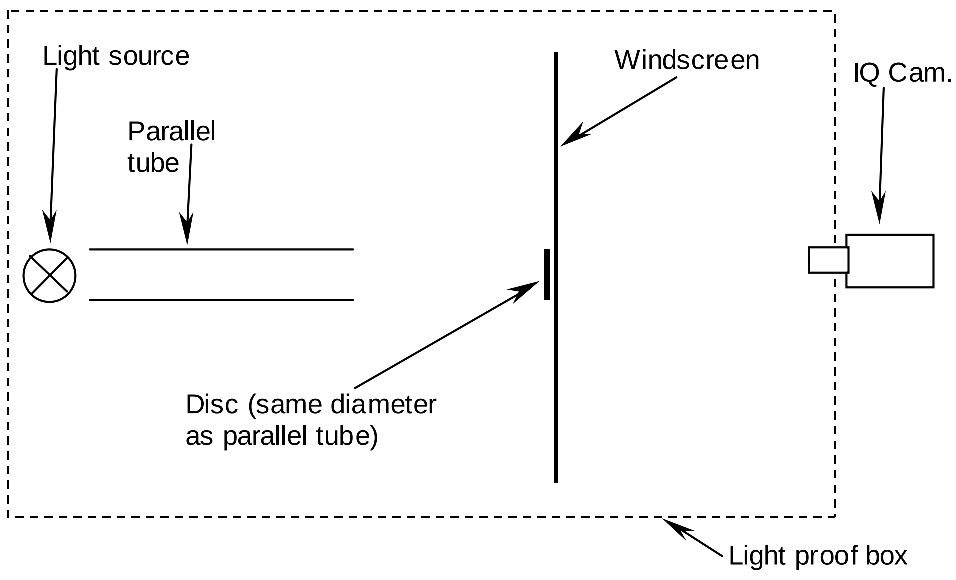
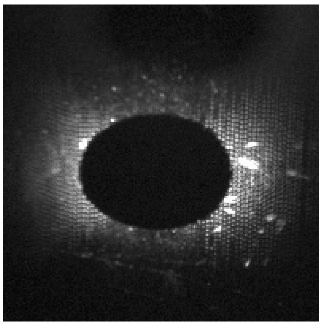
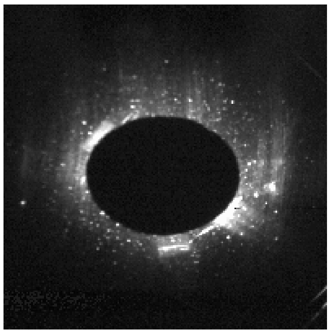


Figure 15: Test apparatus used to measure veiling glare luminance

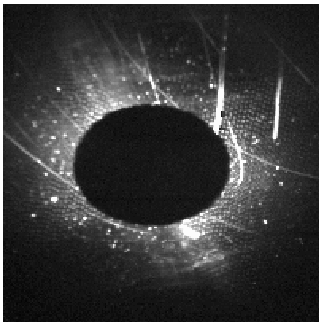
Examples of IQ-Cam images illustrating increased veiling glare luminance as a result of increased mileage exposure and subsequent abrasion are shown below in Figure 16.



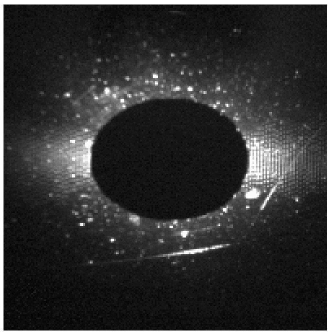
10 miles



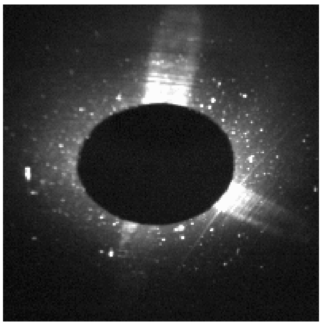
32000 miles



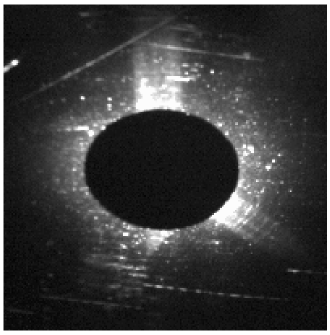
41000 miles



54000 miles



66000 miles



76500 miles

Figure 16: Examples of IQ-Cam images of veiling glare luminance

8.2 Results/Findings

The IQ-Cam software was used to measure the mean luminance of the veiling glare around the disc. When plotted against the windscreen's exposure mileage an increasing trend in the luminance of the veiling glare can be seen as illustrated in Figure 17.

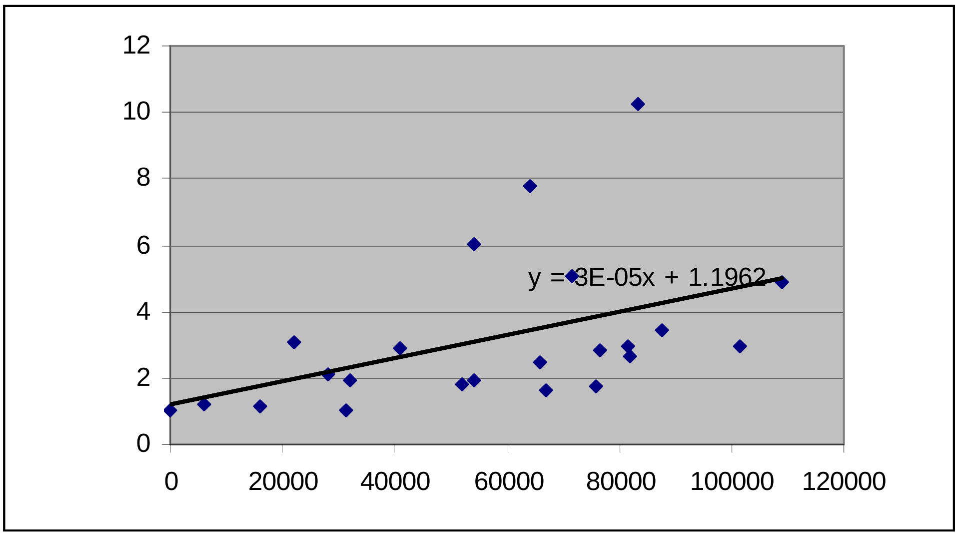


Figure 17a: Relationship between the mean veiling glare luminance and exposure mileage for windscreen sample

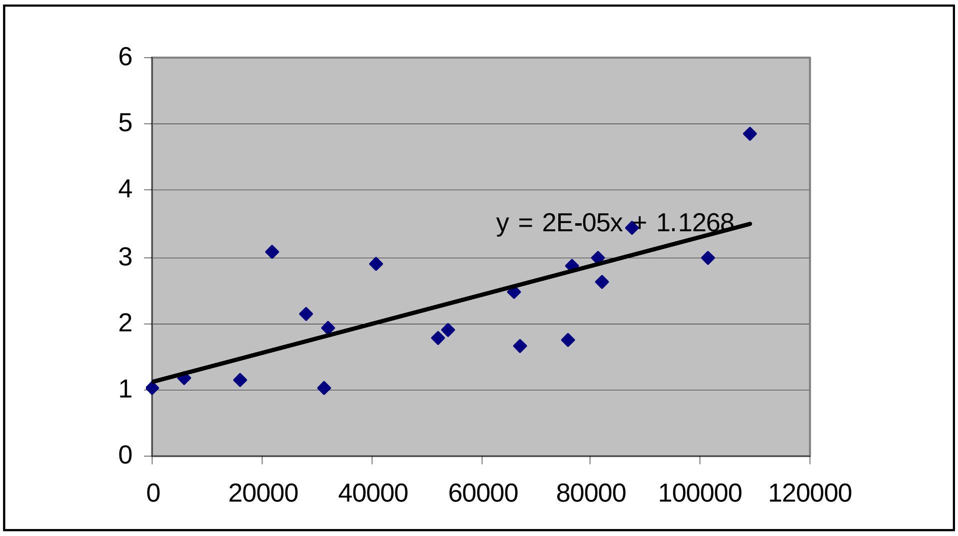


Figure 17b: Relationship between the mean veiling glare luminance and exposure mileage for windscreen sample with outliers removed

The data in Figure 17a indicates that as mileage increases so does the level of veiling glare luminance caused by abrasion. A linear relationship between these variables is broadly defined by the line of best fit for this sample which is plotted on the graph. It can be observed that four windscreens between 50,000 and 90,000 miles lie well above the line of best fit. Outliers, such as these, which show greater than expected abrasion may be caused by factors such as ungaraged parking, predominant use on fast moving roads, predominant use in industrial/construction areas, etc.

Figure 17b shows the same data with the outliers excluded. The line of best fit shows that for every 10,000 miles there is an increase of 0.2cd/m² in veiling glare luminance.

8.3 Conclusions

From a random sample of 24 vehicles with exposure mileage ranging from 10 to just over 100,000 miles, a relationship between mileage and the veiling glare luminance caused by abrasion has been established. Using this data the mean veiling glare luminance for any vehicle can be estimated based on its mileage, assuming that the windscreen is original.

From the threshold veiling glare work programme (refer to Appendix 7) it was concluded that for windscreens of 75% luminous transmission the threshold veiling glare luminance occurred at 5cd/m². Using the equation for the best fit line shown in figure 34b, $y=0.00002x+1.1268$, it can be estimated that a windscreen would need to have been used in the order of 193,660 miles for sufficient abrasion to occur to cause the non-detection of objects on the road in night-time conditions without streetlighting. If installed luminous transmission of 65% which equates to a threshold veiling glare luminance of 3.33cd/m² is used, the resultant mileage is 110,160.

8.4 Recommendations

Based on the worst case condition of night-time ambient lighting without streetlights, the veiling glare luminance caused by abrasion would be sufficient to cause the non detection of targets in the road at:

- 194,000 miles based on 75% luminous transmission,
- 110,000 miles based on 65% luminous transmission (the typical installed luminous transmission of a 75% screen).

Since installed luminous transmission is more representative of the conditions under which drivers drive, the results would recommend that windscreens should be reviewed for replacement at least every 110,000 miles.

Whilst this work programme has developed a reliable methodology to relate abrasion to detection thresholds and thereby define windscreen replacement rates, it would be prudent to increase not only the sample size of windscreens but the number of sample areas to ensure a representative mix. Typical sample areas may include: the southeast, M1/M6 corridors, Wales, major cities, coastal regions, Scottish Highlands, etc. In addition it may also be beneficial to control for different types of usage.

9.0 Windscreen internal contamination trials

An additional source of visual degradation when driving is a greasy layer/film that builds up on the interior surface of a windscreen. This layer has been attributed to a number of contamination sources including, atmospheric pollution drawn in when demisting or ventilating, internal pollution from smoking and food and in the earlier years of a vehicles life from particles given of from interior trim plastics under strong sunlight.

This survey aimed to measure the rate at which this film builds up and its effect on quality of driver vision in terms of light scatter and subsequent increased veiling glare luminance.

9.1 Methodology

The internal and external surfaces of four, installed car windscreens were thoroughly cleaned and the vehicle's mileage recorded. Using a method similar to that used for the windscreen abrasion trials previously described, the mean luminance of the veiling glare around a shielding disc was measured. Subsequent luminance readings were taken at regular intervals at which time only the external surface of the windscreen was cleaned. In this way, the rate at which contamination film built up on the internal surface of the windscreen could be calculated in terms of increasing veiling glare luminance. Refer to figure 18.

A description of the vehicles used in this work is given in Table 25 below.

Table 25: Description of vehicles used in the trial

Vehicle No.	1	2	3	4
Type	Skoda Felicia	Fiat Punto	Renault Scenic	Nissan Sunny
Age	T (1999)	R (1997-98)	R (1997-98)	G (1989-90)
Use Week	Daily commute ≈ 30 miles on rural A and B-roads	Daily commute ≈ 30 miles on rural B-roads	Daily commute ≈ 60 miles on motorway	Daily commute ≈ 5 miles on urban B-roads
Week-end	Rural A and B-roads and some town driving ≈ 50 miles	Generally local journeys on A and B roads ≈ 50 miles	Generally local journeys on A and B roads ≈ 50 miles Occasionally long distance journeys ≈ 300 miles on motorway	Some local journeys on A and B roads ≈ 15 miles Frequent long distance journeys ≈ 200 miles on motorways and major A-roads.
Vent use	Occasional to screen	Infrequent to screen	Occasional to screen	Occasional to screen
Other	Smoking	No smoking	No smoking	No smoking

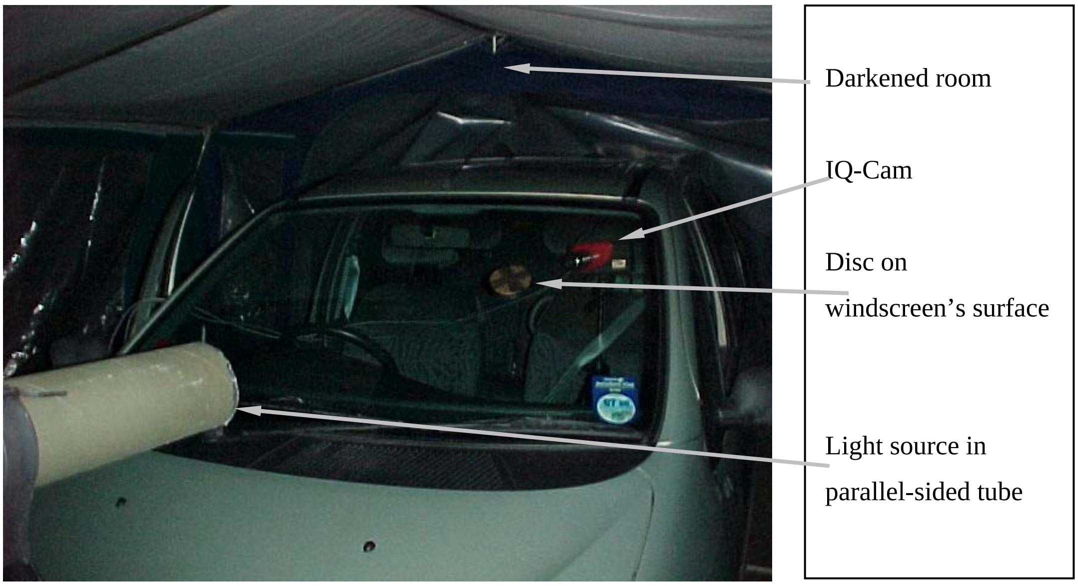
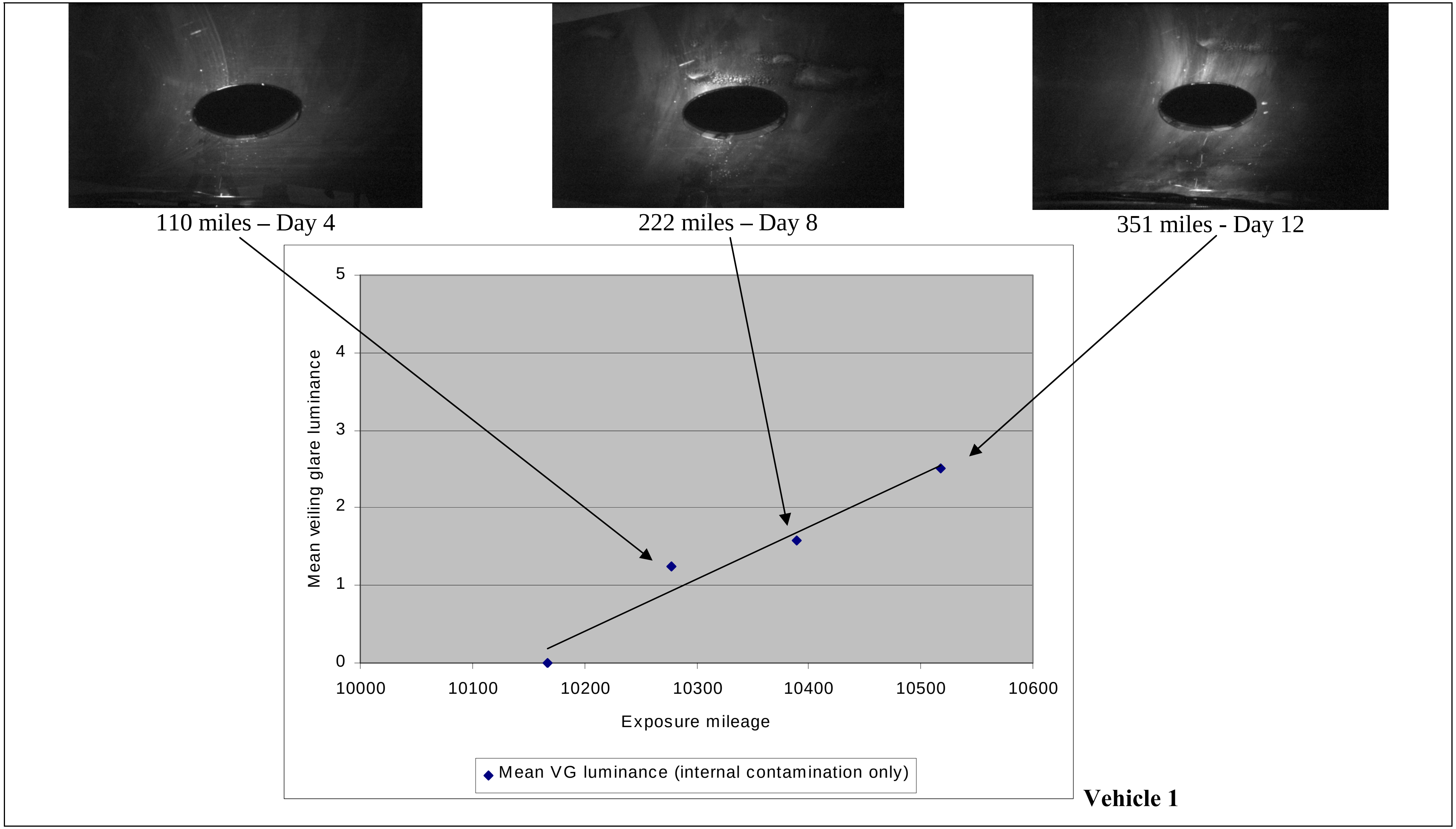


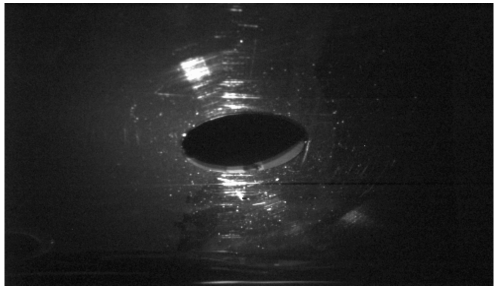
Figure 18: Test apparatus used to measure veiling glare luminance

From data obtained during the windscreen abrasion survey, the internal contamination luminance readings were corrected to remove the effect of abrasion.

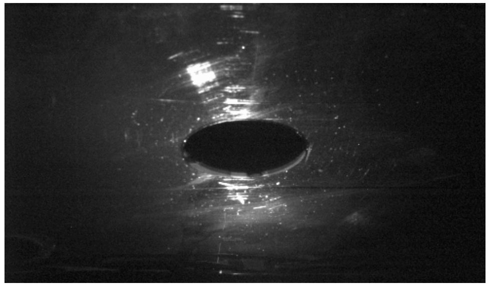
9.2 Results/Findings

The graphs on the following pages show mean veiling glare luminance for each of the four vehicle windscreens plotted against the vehicle's mileage at the time of the measurement. The luminance values have been corrected to remove the probable effect due to abrasion at the given mileage. (The correction factor is based upon the initial measurement and the relationship established from the abrasion survey previously reported). The graphs are accompanied by IQ-Cam images that illustrate the increasing amount of light scatter due to the combination of abrasion and internal contamination build up. Under each image is the mileage and time interval since the initial, 'no internal contamination' reading.

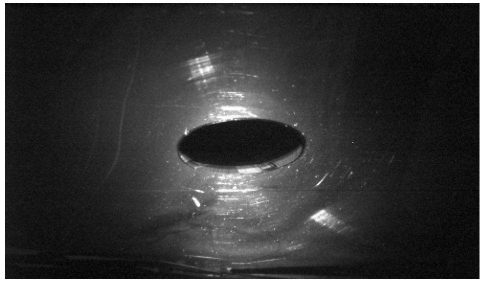

110 miles – Day 4
222 miles – Day 8
351 miles - Day 12
Mean veiling glare luminance
0
1
2
3
4
5
10000
10100
10200
10300
10400
10500
10600
Exposure mileage
Mean VG luminance (internal contamination only)
Vehicle 1



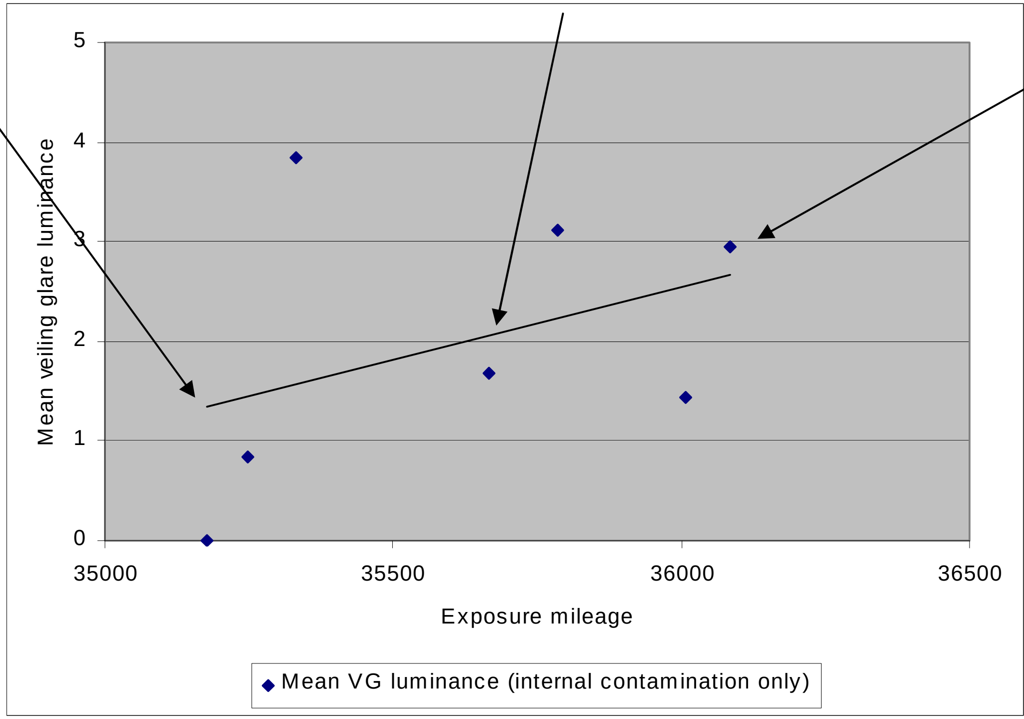
72 miles - Day 3



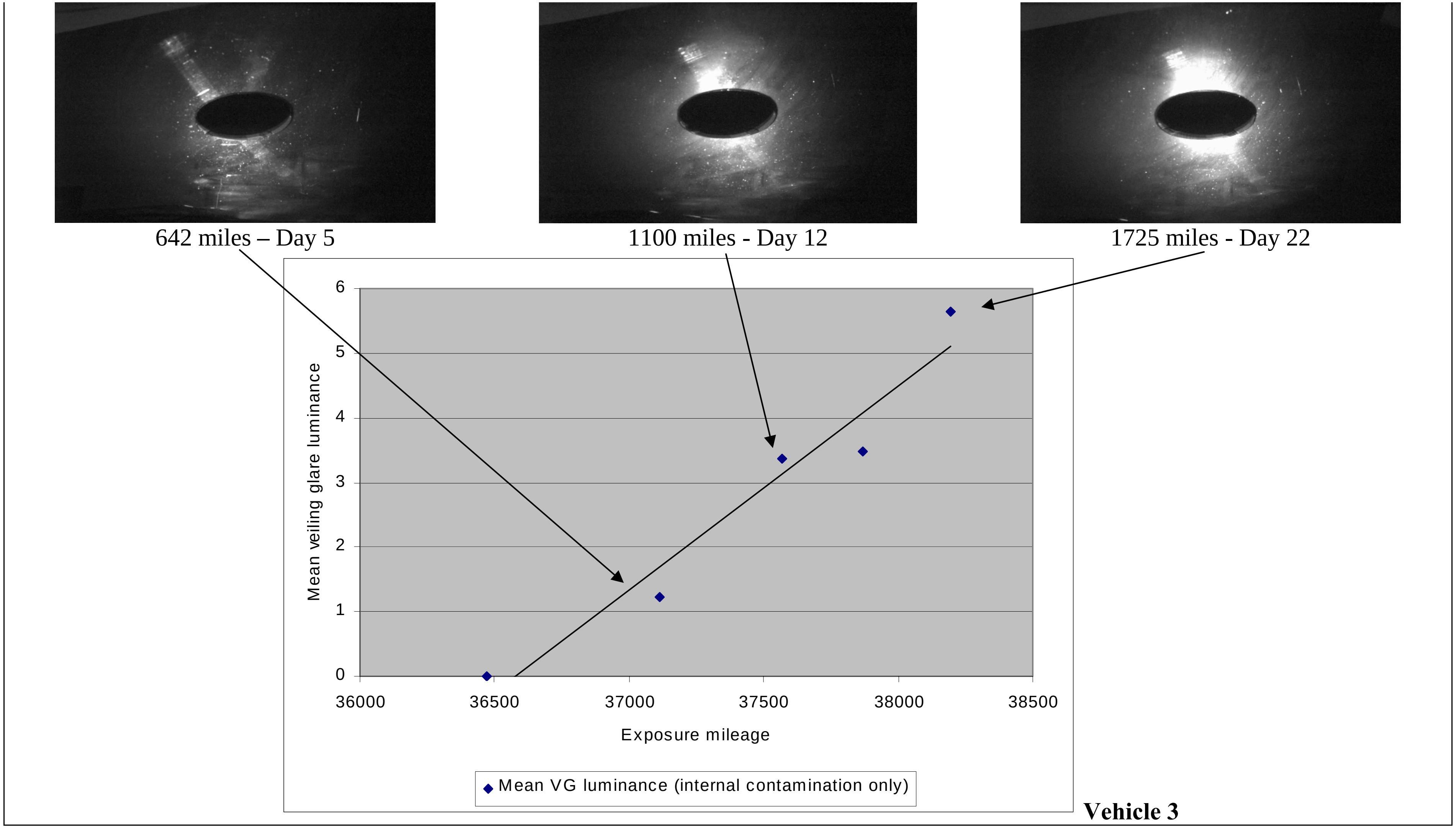
490 miles – Day 10



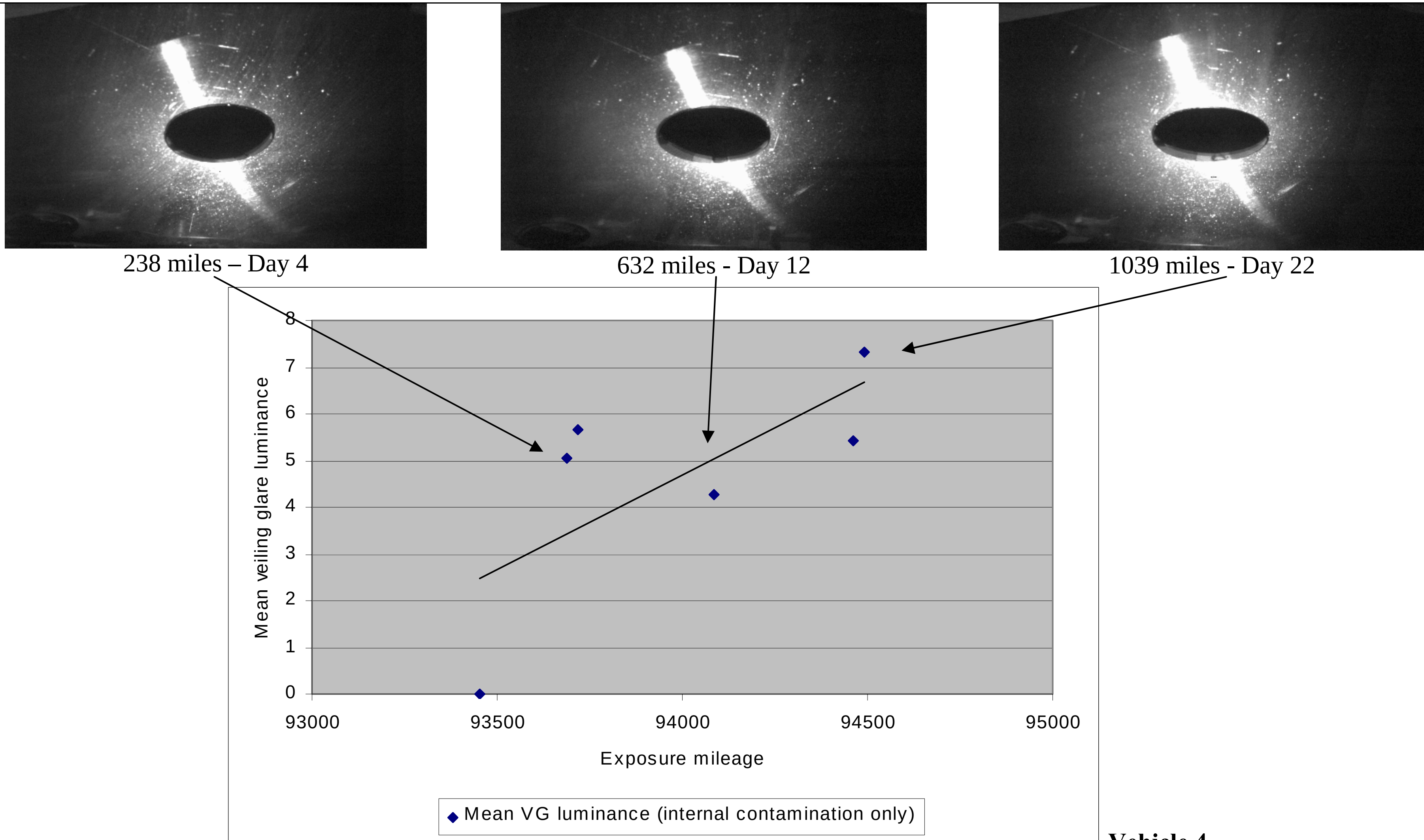
910 miles - Day 24



Vehicle 2


642 miles – Day 5
1100 miles - Day 12
1725 miles - Day 22
Mean veiling glare luminance
Exposure mileage
0
1
2
3
4
5
6
36000
36500
37000
37500
38000
38500
Mean VG luminance (internal contamination only)

Vehicle 3


238 miles – Day 4
632 miles - Day 12
1039 miles - Day 22
Mean veiling glare luminance
0
1
2
3
4
5
6
7
8
93000
93500
94000
94500
95000
Exposure mileage
Mean VG luminance (internal contamination only)

Vehicle 4

Table 26: Windscreen internal contamination survey

	Mileage covered during survey	Duration of survey (days)	Veiling glare luminance increase over survey period (cd/m^2)	Veiling glare luminance increase per 1000miles (cd/m^2)	Veiling glare luminance increase per month (cd/m^2)
Vehicle 1	351	12	2.35	6.7	5.9
Vehicle 2	910	22	1.37	1.5	1.8
Vehicle 3	1725	22	5.52	3.2	7.5
Vehicle 4	1039	22	4.26	4.1	5.8
			Average	3.88	5.25

The previous Figures and Table 26 above indicate that as mileage exposure increases so does internal contamination. The different rates of contamination build up reflect different journey patterns, different use of venting systems, different driver/passenger behaviours (eating, smoking,), etc.

Based on the sample of cars used in this work, an average increase of 3.875cd/m² of veiling glare luminance occurs with every 1,000 miles travelled or 5.25cd/m² every month.

9.3 Conclusions and recommendations

Based on the worst case condition of night-time ambient lighting without streetlights, the veiling glare luminance caused by contamination build-up would cause targets in the road to be at the threshold of detection at the following levels. The threshold detection levels of 5cd/m² for 75% luminous transmission and 3.33cd/m² for 65% luminous transmission were derived from the veiling glare luminance trials reported in Appendix 7.

Table 27: Recommended windscreen cleaning rates

Luminous transmission	Level of contamination build-up at which targets are not detected	
	Miles	**Days**
75%	1290 [(1)]	28 [(2)]
65% (Installed luminous transmission of a 75% screen)	859 [(1)]	19 [(2)]

(1) The average (mean) veiling glare luminance in the windscreen contamination survey was found to be 3.88cd/m² per 1,000 miles. (Refer to previous table). From the veiling glare trials it was found that at 75% transmission, veiling glare reached the threshold at 5cd/m². Therefore veiling glare due to contamination will reach the 5cd/m² threshold at 1,290 miles i.e. (5cd/m² / 3.88cd/m²) x 1,000 miles. At 65% transmission this equates to 859 miles i.e. (3.33cd/m² / 3.88cd/m²) x 1,000 miles.

(2) The average (mean) veiling glare luminance in the windscreen contamination survey was found to be 5.25cd/m² per month. (Refer to previous table). From the veiling glare trials it was found that at 75% transmission, veiling glare reached the threshold at 5cd/m². Therefore veiling glare due to contamination will reach the 5cd/m² threshold at 28 days i.e. (5cd/m² / 5.25cd/m²) x 30 days (one month). At 65% transmission this equates to 19 days i.e. (3.33cd/m² / 5.25cd/m²) x 30 days.

Since installed luminous transmission is more representative of the conditions under which drivers drive, the results would recommend that the interior of windscreens should be cleaned at least every 859 miles or 19 days.

Whilst this work programme has developed a reliable methodology to relate contamination build-up to detection thresholds and thereby define the cleaning rates for windscreen interiors, it would be prudent to undertake future research to increase, not only the sample size of windscreens, but also the number of sample areas to ensure a representative mix.

10.0 Colour identification trials

The aim of this trial was to determine the extent to which coloured lights, typical of those found in the road environment, could be correctly identified when viewed through windscreens of various specifications.

10.1 Methodology

10.1.1 Equipment

The model road was set up to simulate a daytime environment. The purpose of this was to provide a low contrast background for the lights (i.e. worst case scenario). Seven light sources of various colours were used to carry out the evaluation and were viewed through materials with different luminous transmission properties (six in all, plus one "no material" condition). The lights used were sourced from actual lights found in a typical road environment. The luminous transmission properties and light sources used in the trial are displayed below in Table 28.

Table 28: Experimental variables

	Variables
Materials to view through (7)	Luminous transmission:100% (no material), 74.5%, 51%, 33.4%, 19.6%, Colour: Blue, Green
Light sources (7)	Red traffic light Amber traffic light Green traffic light Blue vehicle beacon Green vehicle beacon Amber vehicle indicator Red vehicle brake light

10.1.2 Procedure

The participant was seated at the end of the model road and the view of the road ahead obscured. The first test material and the first target light were put into place and, once the participant was ready, the shutter was dropped to reveal a 200 millisecond glimpse of the road scene and the light on display. The participant was asked to identify the colour of the light seen through the aperture and the data was recorded. This procedure was carried out for all lights. Once all lights had been displayed to the participant, the next test material was assessed by displaying the same seven target lights in a random order. This was repeated for all six test materials plus the “no material” condition.

10.1.3 Participants

Twenty, current UK driving licence holding participants (7 male and 13 female) with a mean age of 44 years (SD 16.3) were recruited from ICE's database of over 400 subjects. Prior to taking part in the trial, all participants were required to carry out a test to identify any colour vision deficiencies they may have had, using the Ishihara test for colour blindness (Ishihara, 1978). No participants were found to have any form of colour blindness.

10.2 Results

Table 29 summarises the data collected from the trials.

Tables 29(a) to 29(d) The responses given by 20 participants for each of the seven lights when viewed through each test material.

(a) Red traffic light and brake light

Test material	Red Traffic Light		Red brake light		
	Red	Orange	Red	Orange	Amber
100%	**20**	0	**20**	0	0
74.5%	**20**	0	**20**	0	0
51%	**20**	0	**19**	0	1
33.4%	**20**	0	**20**	0	0
19.6%	**20**	0	**19**	1	0
Blue	**20**	0	**19**	0	1
Green	**19**	1	**20**	0	0

(b) Blue beacon

Test material	Blue beacon
	Blue
100%	**20**
74.5%	**20**
51%	**20**
33.4%	**20**
19.6%	**20**
Blue	**20**
Green	**20**

(c) Amber traffic light and indicator

Test material	Amber Traffic Light				Amber indicator			
	Amber	Yellow	Orange	Gold	Amber	Yellow	Orange	Gold
100%	**8**	8	3	1	**8**	8	3	1
74.5%	**8**	8	3	1	**8**	8	3	1
51%	**8**	8	3	1	**8**	8	3	1
33.4%	**8**	8	3	1	**8**	8	3	1
19.6%	**6**	10	3	1	**7**	9	3	1
Blue	**7**	9	3	1	**7**	9	3	1
Green	**8**	9	2	1	**8**	9	2	1

(d) Green traffic light and beacon

Test material	Green Traffic Light					Green beacon
	Green	Blue/Green	Blue	Sea Blue	Turquoise	Green
100%	**15**	0	3	1	1	**20**
74.5%	**12**	1	4	1	2	**20**
51%	**14**	1	3	1	1	**20**
33.4%	**14**	0	4	1	1	**20**
19.6%	**13**	1	5	1	0	**20**
Blue	**13**	2	3	1	1	**20**
Green	**15**	1	3	0	1	**20**

10.2.1 Red lights

The four occasions where red was seen as amber or orange, through 19.6% and 51% transmission levels and blue and green tints, were not found to be statistically significant. In other words, the identification of the red lights were found not to be affected when viewed through materials with reduced transmission levels or with green and blue tints.

10.2.2 Blue lights

The results show that all participants saw the blue beacon as blue through all of the test materials. Therefore viewing the colour blue was not found to be affected by transmission level or tint colour.

10.2.3 Amber lights

Only eight of the participants reported seeing the traffic light and the vehicle indicator as amber. However since this occurred when viewing directly and the colours reported by the remaining participants were all in the same area of the colour spectrum, it is suggested that this is not a real effect but one of semantics.

Approximately a quarter of the participants reported seeing a different colour under certain transmission levels and tint colours, although these differences were within the amber region of the colour spectrum and were not found to be statistically significant.

10.2.4 Green lights

Whilst the green beacon was always reported as green, the green traffic light was reported as a variation in the green to blue colour spectrum by a quarter of the participants when viewing directly.

10.3 Conclusion

The results of this experimental study indicate that the transmission levels and blue and green tints used in this work do not significantly affect the ability to identify and distinguish red, amber, blue or green lights typical of those found in the road environment.

11.0 Discussion and recommendations

The driver and rider surveys concerning the quality of vision through windscreens and visors confirmed and prioritised the importance of windscreen/visor tinting, installed light transmission, haze, abrasion and damage/repair to driver/rider vision. This information, and the review of research, was used to define the direction and emphasis of the extensive experimental test programme which was undertaken.

11.1 Luminous transmission

The test programme confirmed the finding from the review of previous research that reduced luminous transmission is only of consequence with low contrast objects under conditions of reduced ambient illumination. Our findings showed that target size and distance from driver and headlamps were critical factors in this. Detection of the disc target at 23m was relatively high with the disc being detected on approximately 75% of occasions. However at 73m, detection rates for the disc were significantly lower and this was constant across all transmission levels. That is to say, the disc at 73m was difficult to see not because of reduced transmission levels but because of reduced ambient lighting. The pedestrian target however was sufficiently large to have improved detection rates over the disc but these were eroded by the reduced contrast of the pedestrian with its background when viewed through materials with reduced luminous transmission. Hence as luminous transmission reduced, the rate of pedestrian detection fell. The decease in the detection rate was significant only when comparing the luminous transmission of 74.5% with that of 19.6% under dawn/dusk and dry, night-time with street-lighting conditions. Further analysis indicated that the lowest level at which luminous transmission is likely to affect detection is in the region of 27%. However this should be evaluated through further field trials which will include older and spectacle wearing participants since research suggests that it is these participants whose detection performance is most likely to be impeded by reduced luminous transmission levels.

Our work to date within this study suggests that in terms of the likelihood of detecting targets on the roadway, there is nothing to be gained by reducing transmission levels lower than 27% under bright daytime conditions, but there is much to be lost if, as the usage surveys suggest could be the case, such visors were used under darkened conditions. Therefore, despite the finding that discomfort glare may be reduced at lower transmission levels, the reduced ability to detect targets when such visors are misused under darkened conditions must be the priority consideration.

In light of these findings, it may be prudent to re-visit the regulations relating to sunglasses.

The conflict of night-time daytime trade-offs as described above may be eliminated in the future due to electrochromatic (light sensitive) glazing. With this technology a low-current AC voltage is applied to a film within the glass or plastic laminate causing the particles within it to align themselves to produce a clear film. Several organisations are researching the application of this technology to vehicle glazing. For motorcyclists there is already a potential solution on the market in the form of a crash helmet with a built in, two-stage, sun visor in which a tinted visor can quickly positioned in and out of view in front of a clear visor as required. In the absence of such devices, a peak may offer some assistance in bright conditions.

With respect to drivers a further consideration needs to be made which relates to installed light transmission. A recent study conducted by ICE Ergonomics (Quigley et al 2000) found that windscreens were typically installed into vehicles at an angle of 59°. Looking through windscreens at such angles increases luminous transmittance losses due to reflection and absorption compared to windscreens viewed vertically at 0°. Previous research (Smith and Bryant, Hills) indicates that luminous transmission is reduced by approximately 10% between 0° and 59°.

11.2 Abrasion and contamination

With respect to abrasion and contamination, ICE Ergonomics developed valid and reliable methods to measure and reproduce their effects. These methods were based on the veiling glare luminance caused by the light scatter resulting from different levels of abrasion and contamination. The results of this work confirmed that the effects of abrasion and contamination are most severe at night and this was used as the basis of the following recommendations. It was considered important for this study to concentrate on these aspects since, unlike screen damage, drivers may be unaware that they are driving with impaired vision nor are there any formal guidelines to assist them in determining this.

11.2.1 Abrasion

Based on our sample vehicles, windscreens should be replaced every 110,000 miles due to the detrimental effects of abrasion.

11.2.2 Contamination

In addition to keeping the outside of the windscreen clean, the inside should also be cleaned. Based on our sample, windscreen interiors should be cleaned at least every 859 miles or 19 days. Comparison with the results of the drivers' survey indicates that 6 from 26 drivers, about 20%, do not clean the interior of their screen this frequently. Since contamination build-up accumulates gradually over time, drivers may not always be aware that they are driving with impaired vision and since no formal screen clean guidelines exist, it was important to fully address this aspect of the study.

The above two recommendations provide the initial basis for guidelines which currently do not exist. However to increase their representativeness consideration should be given to carrying out further research. Refer to the next section for details of this.

11.3 Reflection

A further recommendation from this work, based on the drivers survey, is that windscreen reflection is an area which should also be considered for future investigation. Previous research conducted by Allen et al 1996 recommends improving contrast and reducing glare by covering the vehicles dash with a dull black cloth. Removing objects from the dash which reduce contrast should also be encouraged.

11.4 Fogging

A survey carried out by the Health and Safety Executive (HSE) found that fogging was the main reason why eye protectors were not being used when needed. (This supports the finding from the survey of riders conducted as part of this study which found that ‘misting’ was a problem associated with visor use). A method which could be used to measure the amount of time it took for the clarity of a viewed image to be reduced to 50% and 75% of its original value was devised by Vaughan et al (undated) in response to the HSE survey. Further investigation should be made to determine if this could form the basis of a future test for motorcycle visors for reduced clarity due to fogging.

12.0 Future work

The work undertaken in this study has indicated areas requiring further research; these are given below.

12.1 Luminous transmission

The extrapolated findings regarding the lower level of luminous transmission of 27% discussed in section 6.13 were based on theoretical calculations, which were in turn based on laboratory tests. Considering the potential safety implications, it is strongly advised that these findings and any recommendations based on them are validated by further objective and, potentially, real-world trials. Research by Rompe and Engel (in Taylor undated) indicates that spectacle wearers have more difficulty detecting low contrast targets in low ambient lighting conditions through tinted materials. Age was also found to have a similar effect (Allen et al 1996 and the AA). It should therefore be ensured that these categories of drivers are represented within the validation trials in sufficient number to enable analysis of the contribution of these factors.

12.2 Abrasion and contamination

Whilst this work programme has developed a reliable methodology to relate abrasion to detection thresholds and thereby define windscreen replacement rates (refer to the section relating to the windscreen abrasion trials), it would be prudent to increase not only the sample size of windscreens but the number of sample areas to ensure a representative mix. Typical sample areas may include: the southeast, M1/M6 corridors, Wales, major cities, coastal regions, Scottish Highlands, etc. In addition it may also be beneficial to control for different types of usage.

12.3 Reflection

Since there is little existing research concerning the effect of reflections, it would be valuable to investigate this area further . This was an areas of particular concern for the respondents in our driver survey with 26 from 36 respondents stating that they had experienced problems due to reflections on the windscreen. Future research should identify the sources of reflection, quantify their effects in terms of veiling glare and target detection, investigate solutions and provide guidelines to vehicle manufacturers and users as to how to reduce the disbenefits of reflections.

12.4 Fogging

Further research is required to quantify the effect of fogging which has been identified by two independent bodies (the Health and Safety Executive and ICE Ergonomics as part of this study) as an impediment to visor use. Based on ICE’s working concerning veiling glare threshold levels and the work of Vaughan et al (undated) which measures the amount of time taken for the clarity of a viewed image to be reduced to 50% and 75%, much of the research and development of relevant evaluation methodologies appears to be in place for future research.

The drivers’ survey indicated that one third of drivers use the car’s fan to clear the windscreen *while driving*. Acceptable minimum levels to which the screen must be demisted in the shortest possible time, and the windscreen areas to whch this should be applied, should be investigated.

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