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Conspicuity of horses and riders on roads

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Contents

Abstract

The literature on visibility and conspicuity was reviewed, in order that the best advice for horse riders could be provided with the aim of increasing their safety (and that of their mounts) when riding on public roads. The main scenario considered was that which occurs when riders are approached by motor vehicles from behind, often at speed. Research with horses and with other vulnerable road user groups (pedestrians, cyclists, and motorcyclists) was included, and knowledge regarding the human visual system, in relation to object detection and judgement of approach, was considered. Three recommendations were made. First, speed limits on national speed limit roads with frequent equestrian activity should be reduced. Second, riders should choose to wear lights wherever possible, ideally in a pattern that highlights their width (lights on their shoulders and the flanks of their horse, for example). Third, in the absence of lights, riders should wear high visibility and reflective clothing, choosing a colour appropriate for their riding environment.

Executive summary

The British Horse Society (BHS) aims to "...protect and promote the interests of all horses and those who care about them…" Part of this requires that evidence-based advice is available to improve safety.

This report seeks to provide a basis for BHS advice regarding one topic on which it is often asked to comment; the visibility and conspicuity of riders and their mounts when riding on public roads. It achieves this by providing a review of relevant theory and evidence relating to the impact that interventions such as high visibility clothing and lighting may have on road safety for horses and their riders.

The basic premise for the work is that horse riders should benefit from evidence-based advice about what they can do to achieve two outcomes:

1. Maximise the likelihood that other road users (especially motorised road users) will detect them
2. Maximise the likelihood that other road users will be able to accurately judge their approach (especially when approaching a horse from behind and at speed)

Very little evidence directly researching the issue with horses was found. Evidence from research with other vulnerable groups such as pedestrians, cyclists and motorcyclists was then reviewed, along with formal knowledge and theory relating to the human visual system, both in terms of detection and judgement of approach.

On the basis of the evidence reviewed, the following three recommendations are made, in order of importance:

1. **Speed limits on roads with significant horse and rider activity should be reduced, and enforced.** The optical geometry alone argues that it is unwise to have drivers travelling at 60mph on roads that are routinely and regularly used by horse riders, especially in conditions of reduced lighting.
2. **Riders should utilise clothing that contains LED lights wherever feasible.** Ideally this should cover as much of the rider and horse as possible, prioritising covering width extent above height. A suggested pattern would be two red LEDs on the shoulders of the rider, and two on the sides of the horse's flank, all facing backwards. White LEDs facing forwards in a similar pattern would help with frontal approaches.
3. **Riders should use bright and reflective safety clothing wherever feasible.** Again ideally this should cover as much of the rider and horse as possible, prioritising covering width extent above height, although also on the legs to introduce 'biological motion' cues. There is no firm evidence to say one colour is more visible than any other across multiple environments; riders should consider the dominant colours in their riding environment (e.g. coloured foliage and crops, backgrounds associated with sunsets) and choose a colour which will provide contrast accordingly.

The report suggests that BHS can take forward these recommendations through lobbying of national and regional road authorities (Recommendation 1) and through advice circulated to its members (Recommendations 2 and 3).

1 Introduction

The British Horse Society (BHS) is a charity which aims to "...protect and promote the interests of all horses and those who care about them…"[1], and the BHS vision is that "Every Horse is respected, protected and enjoyed by knowledgeable caring people."

One of the objectives supporting this vision is:

"To promote and advance the education, training and safety of the public in all matters relating to the horse."[2]

In support of this aim, this report seeks to provide a basis for BHS advice regarding the visibility and conspicuity of riders and their mounts when riding on public roads. It achieves this by providing a review of relevant theory and evidence relating to the impact that interventions such as high visibility clothing and lighting may have on road safety for horses and their riders.

The basic premise for the work is that horse riders should benefit from evidence-based advice about what they can do to achieve two outcomes:

1. Maximise the likelihood that other road users (especially motorised road users) will detect them
2. Maximise the likelihood that other road users will be able to accurately judge their approach (especially when approaching a horse from behind[3] and at speed)

Both of these outcomes (and some others discussed, such as reduced traffic speed) have the potential to reduce the likelihood of dangerous interactions and collisions between other road users and horses.

We begin by reviewing the literature that has looked directly at the impact of horse visibility and conspicuity aids on safety outcomes (Section 2). It is quickly established that there is almost no literature which directly addresses this issue. In light of this, we then begin a canter through the wider road safety literature by discussing the concepts of detection and judgement of approach, and by considering evidence from research with other vulnerable road user groups to see which interventions have had success. We then apply these findings, and relevant knowledge regarding the human visual system, to an important risk situation for horse riders on roads – the approach of vehicles towards them at speed (Section 3). Finally overall conclusions based on the work reported in the previous chapters, and recommendations for the BHS and its members, are presented (Section 4).

[1] http://www.bhs.org.uk/our-charity - retrieved 03/10/2017

[2] http://www.bhs.org.uk/our-charity/our-purpose/our-mission - retrieved 03/10/2017

[3] Motorised vehicles approaching horses from the front at speed are also an issue even though in many cases there will be additional space between the passing vehicle and the horse. The perceptual issues discussed in the paper are applicable to both scenarios, although we focus our discussion on approaches from the rear for simplicity.

2 Evidence relating to conspicuity aids and the safety of horses

There is widespread anecdotal evidence in the riding community that horse riders frequently experience dangerous interactions, near-collisions, and collisions with other road users on the road. The BHS itself has data on this, in the form of self-reported incidents on its website.[4] In addition, the BHS has reported that its members often seek advice on potential countermeasures (especially as related to conspicuous and high visibility clothing).

It is worth defining the terms visibility and conspicuity. Visibility is typically defined as the ease with which an object can be detected when the observer knows its position; conspicuity on the other hand is typically defined as the extent to which something stands out from its background either when people are searching for it (so-called 'search conspicuity') or when they are not searching for it but it simply grabs their attention (so-called 'attention conspicuity') (Langham & Moberly, 2003). The majority of research in the wider road safety literature tends to use detection time or distance as an index of conspicuity (typically under 'search' instructions) although there is some work looking at other outcome measures, typically with pedestrians, cyclists or motorcyclists (see Section 3.2.1).

There is, unfortunately, very little evidence that directly addresses the issue of visibility and conspicuity of horses on collisions.

Chapman and Musselwhite (2011) examined the attitudes and reported behaviour of drivers and horse riders through focus groups of both frequent horse riders and drivers with little or no horse riding experience. The topic areas discussed covered hazard perception, risk perception, emotion, attitudes to sharing the road and empathy. Many of the findings were around driver-targeted actions such as the need to address the deficit in driver knowledge and skills relating to horses and promoting empathy. However the focus groups also suggested that riders' clothing and their use of safety equipment can affect the behaviour of other road users. Drivers in the focus groups acknowledged that a judgement is made regarding the level of control that a rider has over their horse (although this level of control is over-estimated) and that certain factors can affect that judgement; for example a child is usually judged to be less in control and given more space during an overtaking manoeuvre. However it is not clear whether the wearing of 'safety clothing' by riders implies a greater or lower level of control over the horse, and therefore how drivers' behaviour may be best influenced.

There is no legislation governing Personal Protective Equipment (PPE) of any kind for riders on highways, except a requirement for children under the age of 14 to wear a helmet (*Horses (Protective Headgear for Young Riders) Act 1990, Section 1*). The Highway Code recommends use of light-coloured or fluorescent clothing in daylight (*Highway Code, Rule 50*). It also suggests that riders avoid riding at night or in poor visibility if possible and provides the following advice regarding clothing and lights:

> *It is safer not to ride on the road at night or in poor visibility, but if you do, make sure you wear reflective clothing and your horse has reflective bands above the fetlock*

[4] http://www.bhs.org.uk/safety-and-accidents/report-an-incident

> *joints. A light which shows white to the front and red to the rear should be fitted, with a band, to the rider's right arm and/or leg/riding boot. If you are leading a horse at night, carry a light in your right hand, showing white to the front and red to the rear, and wear reflective clothing on both you and your horse. It is strongly recommended that a fluorescent/reflective tail guard is also worn by your horse. (Highway Code, Rule 51)*

Many equestrian associations, such as the British Horse Society and the British Equestrian Trade Association, and the riding community more generally, also recognise the risk that riders are subject to on the road and have issued advice on clothing and visibility. Existing advice tends to be broadly similar to the approach outlined in the Highway Code, suggesting the use of high-visibility materials for both horse and rider.

There is extremely limited research available that is targeted specifically at the conspicuity or visibility of horse-rider combinations on roads. Three studies of note are to be found in the literature, carried out by the same team of researchers and presented at the annual International Equitation Science conference (Scofield, Savin & Randle, 2013; 2014; 2016).

The first two studies were survey-based using questionnaires that were distributed via equine websites and social media in the UK. In the first of these, Scofield *et al.* (2013) aimed to investigate the relationship between the occurrences of near misses and the use of fluorescent (or reflective) equipment on riders and horses. Since this was questionnaire-based, both the near misses and use of equipment were self-reported.

60.3% of riders reported experiencing a near miss with traffic in the previous year. There was no statistically significant relationship between either riders or horses wearing fluorescent materials and the incidence of near misses. However there was a statistically significant relationship between riders wearing lights or not and the incidence of near misses. The research therefore suggested that lights should possibly be recommended when riding on the roads.

The second study (Scofield *et al.*, 2014) aimed to investigate the factors that might affect incidences of near misses. The questionnaires covered the wearing of fluorescent or reflective equipment, horse colour, demographic information and the environment where the near miss occurred.

66.2% of riders reported experiencing a near miss with traffic in the previous year. As in the previous study, there was no significant relationship between the wearing of fluorescent equipment and the incidence of near misses. This was true for both horse and rider, and the horse-rider combination. Also as before, riders wearing lights were shown to report significantly fewer incidences of near misses. Horses of broken colour (that is, piebald or skewbald) experienced significantly fewer near misses than horses of block colour.

These two studies therefore suggests two elements that may be worth considering in providing a possible safety advantage when riding on the road network; these are the addition of lights to any equipment worn and the selection of horses of broken colour.

The third study (Scofield *et al.*, 2016) was to determine the effectiveness of two different conspicuity tabards in terms of visual identification time by drivers. Drivers (both with and without horse riding experience) were shown images of a horse-rider combination with a dark-coloured tabard, a fluorescent tabard and a black/white tabard (mimicking the coat of a piebald horse) and asked to indicate when they saw the image. The results showed no statistically significant difference between response times for the fluorescent tabard and the black/white tabard, however there was a significant difference between the times for the black/white tabard and the dark colour, and between the fluorescent tabard and the dark colour, with the dark tabard being associated with longer response times (i.e. slower detection).

This third study indicates that drivers may have a quicker response time when presented with a horse-rider combination wearing either a fluorescent or broken-colour tabard than with a dark colour tabard (or none). These findings would not necessarily be replicated in a live environment, nor would the drivers' behaviours necessarily change as a result of the quicker identification; however it is possible that such clothing may allow a driver additional time in which to perceive the hazard and respond.

In summary, there appears to be little or no direct evidence regarding the effectiveness of popular conspicuity measures currently used by horse riders[5]. The few studies discussed above provide some indications as to elements which may be of importance in reducing risk, and indeed those factors which appear to have no effect, but this area is remarkably under-investigated and much more research is required.

In the absence of much direct evidence, we now turn our attention to applying what is known from studies of detection and judgement of approach in other vulnerable road user groups, such as pedestrians, cyclists and motorcyclists.

[5] Other examples of clothing worn by riders include vests with text designed to alert drivers to the possibility that riders may be filming (e.g. "I've got a camera"), with direct instructions (e.g. "Please Pass Wide and Slow") or the word "Polite" (which might be argued as targeting an affective state designed to promote safer driving, or might be argued as being perceptually similar to the word "Police"). We found no evidence examining the impact of such clothing on horse safety, although a single study on cyclists does exist – see Walker, Garrard and Jowitt (2014).

3 Detection and judgement of approach – theory, evidence from other vulnerable road user groups, and calculations

3.1 Detection and judgement of approach

It is self-evident that drivers need to detect other road users if they are to avoid collisions. Detection is especially important when considering vulnerable road users, since by their nature collisions with such road users tend to involve injuries of greater severity. However with vulnerable road users, the relevance of another factor – judgement of approach – also becomes especially important. This is mainly because vulnerable road users tend to be small (relative to cars, lorries, vans and so-on) and in addition to small objects being more difficult to detect, it is also more difficult for observers to judge their approach speed, and correspondingly, the amount of time it will take them to arrive at the observer's position[6] (Delucia, 1991; Delucia, Kaiser, Bush, Meyer & Sweet, 2003; Caird & Hancock, 1994; Horswill, Helman, Ardiles & Wann, 2005).

There are substantial applied research literatures both on detection and judgement of approach of vulnerable road users. Research looking at the former tends to be interested in ways in which the visibility and conspicuity of vulnerable road users can be increased to aid detection. Research looking at the latter tends to be concerned with finding ways in which the basic perceptual information that the visual system needs in order to judge speed and time to arrival can be more readily provided to observers.

A comprehensive review of these wider literatures is outside of the scope of this review, but consideration of the main findings is useful, as we can then see how they are relevant to the specific risk situation of interest here for horse riders on the roads – those in which motor vehicles are approaching them from behind, at speed.

3.2 Relevant evidence from research other vulnerable road user groups

3.2.1 Detection

The issue of visibility and conspicuity has been studied extensively in road safety, especially as it relates to pedestrians, cyclists and motorcyclists.

3.2.1.1 Pedestrians

Kwan and Mapstone (2006) undertook a systematic review of interventions designed to increase pedestrian and cyclist visibility and conspicuity. Although the quality of studies reviewed was generally weak, a consistent picture emerged. They found that fluorescent materials improved detection in daytime, and flashing lights, lamps, and retroreflective

[6] Typically, research into judgement of approach speed or time-to-arrival estimation is concerned with a vulnerable road user such as a motorcycle approaching the observer's position. However as noted in Appendix A it can be shown that there is very little difference between that scenario and an observer approaching a vulnerable road user; the optical calculations necessary to estimate arrival time are essentially the same.

materials improved detection at night. Retroreflective ‘bio-motion’ configurations (which take advantage of movements of pedestrians’ limbs) were found to be particularly effective in enhancing recognition.

When drivers are actively searching for pedestrians who are wearing high visibility or reflective clothing, detection distances are substantial. Sayer and Mefford (2005) for example showed that pedestrians wearing high visibility vests in daytime conditions were detected around 195m away in high complexity scenes such as towns, and around 266m away in simpler surroundings like rural roads. An earlier study under night time conditions (Seyer & Mefford, 2004) showed that drivers detected pedestrians wearing reflective strips in mock roadworks from over 300m away; detection distances for dark clothing (as a comparison) were around 100m.

Such distances correspond to potentially large safety margins; for example at 60mph a detection distance of around 300m would provide around 12 seconds of decision time. However it is not likely that drivers are always actively searching for pedestrians, or indeed for any other vulnerable road user group. Work that has attempted to look at ‘attention conspicuity’ suggests that detection rates and detection distances are likely to be much lower than studies using search conspicuity instructions. A classic study by Cole and Hughes (1984) showed that drivers’ detection for reflective discs was around three times as likely under ‘search’ conditions as under conditions in which drivers were simply told to report anything that grabbed their attention. Helman and Palmer (2010) showed that when drivers approached dummies wearing high visibility and reflective clothing on a test track at night, and were asked to report the things grabbing their attention, detection distance for the dummies was between 25m and 40m depending on whether there was ambient lighting present. These distances are clearly associated with much smaller safety margins than those found in ‘search conspicuity’ studies.

Another important finding from this literature is that pedestrians tend to overestimate the extent to which they are visible to other road users, especially at night and when they are not wearing any high visibility or reflective clothing (Tyrell, Patten & Brooks, 2002). The extent to which this is true of horse riders is unknown, but might be worthy of investigation.

3.2.1.2 Cyclists

The findings from Kwan and Mapstone (2006) are again relevant, showing that fluorescent materials in daytime, and flashing lights, lamps, and retroreflective materials at night, aid in detection of both pedestrians and cyclists.

A recently-completed randomised controlled trial (Lahrmann, Madsen, Olesen, Madsen & Hels, in press) addressed the main limitation noted in the Kwan and Mapstone systematic review; the authors studied collision involvement in approximately 3,400 cyclists who wore a yellow jacket when cycling, and around the same number who did not. The study showed around a 38% reduction in personal injury accidents in the jacket wearing group, when response bias was controlled. This study presents strong evidence that wearing high visibility clothing can reduce collision risk in cyclists.

3.2.1.3 Motorcyclists

A review of motorcycle 'right of way' accidents (Pai, 2011) concluded that the two dominant causes were poor conspicuity of motorcyclists, and poor judgement of their approach speed by observers. Reviews of high visibility clothing and various lighting interventions have concluded that they have the potential to increase detection during the day and at night, and therefore to increase safety (e.g. Helman, Weare, Palmer & Fernandéz-Medina, 2012).

3.2.2 Judgement of approach

The majority of road safety research into judgement of approach speed (and time to arrival) has been concerned with collisions involving 'right of way' violations in front of motorcycles, since this factor is believed to be a major contributor to such collisions (Pai, 2011).

There are two key findings relevant to the issue here. First, observers overestimate (relative to their estimate for larger vehicles) the time to arrival for smaller vehicles such as motorcycles (Caird & Hancock, 1994; Horswill et al., 2005). Second, judgements are even worse at night, when vehicle contours are unavailable (or less available) to assist in estimates of approach speed (Gould, Poulter, Helman & Wann, 2012b).

There is some evidence that lighting treatments which seek to address both of these issues (especially at night) can lead to safety benefits in motorcyclists (Gould et al., 2012b; Helman, Palmer, Haines & Reeves, 2013). Helman et al. (2013) for example showed in a real world observation study that drivers report an extra 0.5-0.75 second safety margin when making gap acceptance decisions in front of an approaching motorcycle with extra lighting designed to increase horizontal extent.

3.3 Specific considerations for horses and their riders

In the following sections we consider the critical issues of detection and judgement of rate of approach (along with some fundamental knowledge about the human visual system) in relation to the scenario of most interest to the report – vehicles approaching horses (especially from behind and at speed). The main points are made in this section, with more detailed discussion in Appendix A.

3.3.1 Considerations for detection

3.3.1.1 Reflective materials

Detection rates should be enhanced by the addition of any features that introduce a step change in luminance, colour or contrast with the background, and the evidence from other road user groups suggests that reflective and high visibility materials may be beneficial. The extent to which a 'step change' is achieved depends upon the specific environment and lighting conditions. For example reflective materials are highly effective at night, but they rely upon the reflective material falling within the throw of the headlights of oncoming vehicles. If the conditions are early evening and a driver has not turned on their headlights, then the reflective material is ineffective because the ambient light is low and the amount reflected towards the driver is very small. The same holds for good daylight conditions. For the example of a horse and rider there is also the factor of the vertical height of the reflective material. In those cases when a horse and rider are still on the road in twilight or night-time, the height of a rider is too high for a reflective vest to be optimally illuminated by dipped headlights and would only be optimally illuminated by full-beam lights. If there were a scenario where twilight journeys were common then a lower placement of reflective material would be optimal, such as the use of leg bands. These also introduce subtle biological motion cues from the horses walking action which have been shown to have additional benefits to alert drivers when used with human pedestrians (Kwan & Mapstone, 2006).

3.3.1.2 Coloured vests

Given the need for a directional light source to optimize the benefit of a reflective vest, one of the clearest benefits of current commercial safety-wear is the contrast they provide with the surrounding environment. In vision research, the term contrast is most commonly used to refer to step changes in the lightness/luminance of a surface (e.g. black vs white). It is the case that most safety vests reflect more ambient light than a number of surrounding features, such as hedgerows and verges, but there are a number of features that may be in the scene that reflect similar amounts of ambient light, such as the polished surfaces of vehicles. In that respect the major benefit of safety clothing is likely to be the colour-contrast with the background, there are relatively few features in everyday rural scenes that are bright 'fluorescent' yellow, orange or pink, but in some visual scenes there could be extensive banks of these colours. At particular times of year there are large areas of bright yellow surrounding European roads due to oil-seed rape or sunflower cultivation. Orange and pink crops are less common, but in a setting where there is a low sun dropping toward a picturesque red/orange sunset it may be that yellow is more conspicuous than pink or orange. How detectable different coloured vests are in different rural settings is an empirical question. There have been studies undertaken on the effectiveness of safety vests, as previously discussed (e.g. for motorcycles or cyclists) but not with subtle manipulations such as the detection of a cyclist in a yellow vest passing a field of sun-flowers, or in a pink vest cast against a red sunset.

3.3.1.3 Lighting

A simple way to offset the issue that reflective material requires direct illumination for it to be effective, is to provide the directional light beam back to the driver from a powered light source. There is now a wide array of very light-weight, high luminance LEDs that provide illumination for more than 100 hours from small cell batteries. These provide a conspicuous feature, irrespective of the ambient light levels and without the reliance on car headlights. They can be used to highlight the width of the horse and rider (see Gould et al., 2012a and Appendix A for discussion of potential importance of horizontal over vertical cues) and a number of current devices can be set to an alternating motion/flash pattern which can provide an additional alerting feature. A number of safety conscious cyclists now use flashing rear lights throughout the day and although there haven't been controlled studies as to whether they are effective during good daylight conditions, the overhead in terms of weight or running cost is very small and they will certainly add benefit if the light levels start to dip before the rider completes their journey.

3.3.2 Considerations for judgement of approach

Humans do not sense distance directly; this is unfortunate given the importance of knowing time-to-arrival in driving. Fortunately research shows that humans use an optical short-cut to judging arrival time. Provided the driver has an estimate of the optical size of an object/hazard, then if they can also estimate the rate of expansion of the object then the ratio of the two can also give an estimate of time to arrival. The optical size is the patch that the object projects onto the back of the retina, and its expansion is the rate at which it is increasing in size on the retina, which from here on we will call 'looming'.

In the scenario we are considering (a driver approaching a horse and rider from behind) it is looming which will help the driver to judge time-to-arrival (i.e. the time it will take for the driver to arrive at the horse's position). Because of the way in which the mathematics of looming works (see Appendix A), larger objects loom at a higher rate than smaller objects, and the higher the approach speed the greater the rate of looming. There are two important caveats however.

First, for a given time-to-arrival (i.e. the time available for a driver to reduce speed in good time, in preparation for passing) at higher approach speeds the image size on the retina will be smaller since the horse will be further away. Thus for a given time-to-arrival, looming rate will be LOWER for a faster approach speed. Using an example of two approach speeds will help to illustrate this. At 60mph, a driver approaching a horse approximately 0.6m wide[7] will experience a looming rate of approx. 0.08 deg/s when four seconds (around 107m) behind. At an approach speed of 40mph with a four second time-to-arrival (around 71m behind the horse) the looming rate will be approx. 0.12 deg/s. So at the same time point before arrival the image of the horse is looming faster for the SLOWER driver.

The second caveat is that the human visual system can only detect looming rates above a certain threshold. This is especially important in lower light conditions since the 0.6m wide horse and rider may begin to appear smaller as the extent of its outline becomes less detectable. If all that is detectable is a single rider vest, or small light source (for example a helmet light, or tail light) then the rate of looming at a given time-to-arrival may begin to fall below the threshold of what can be detected by the driver (again see Appendix A for examples, and estimates of what this threshold might be in different contexts).

In summary:

I. When drivers are travelling faster, they are more likely to fail to notice that it is time to initiate their braking action in order to slow to a cautious speed before they get to within 40-50m of a horse. This may result in late braking or inadequate braking on approaching a horse and rider.
II. When the object being approached has a smaller area that is visible at a distance then the errors highlighted above will scale upwards.

Slower approach speeds and high-visibility equipment which increase the image size of the horse and rider, should both therefore help drivers to judge looming rate.

[7] See Appendix A for a discussion of the fact that width, rather than height, seems to be most important for detection of judgement of approach.

4 Recommendations

This report sought to provide evidence-based recommendations on the conspicuity and visibility of horses, which could be used by the British Horse Society to support its members.

After reviewing the sparse road safety literature which directly addresses the visibility and conspicuity of horses and riders, the report covered research with a range of other vulnerable road user groups, and considered the human visual system in respect of the detection of other road users and judgement of their approach. Taking all of the research and knowledge reviewed into account, the report makes the following three recommendations[8], focused on the important risk scenario of motor vehicles approaching a horse at speed, and in order of importance:

1. **Speed limits on roads with significant horse and rider activity should be reduced, and enforced.** The optical geometry alone argues that it is unwise to have drivers travelling at 60mph on roads that are routinely and regularly used by horse riders, especially in conditions of reduced lighting.
2. **Riders should utilise clothing that contains LED lights wherever feasible.** Ideally this should cover as much of the rider and horse as possible, prioritising covering width extent above height. A suggested pattern would be two red LEDs on the shoulders of the rider, and two on the sides of the horse's flank, all facing backwards. White LEDs facing forwards in a similar pattern would help with frontal approaches.
3. **Riders should use bright and reflective safety clothing wherever feasible[9].** Again ideally this should cover as much of the rider and horse as possible, prioritising covering width extent above height, although also on the legs to introduce 'biological motion' cues. There is no firm evidence to say one colour is more visible than any other across multiple environments; riders should consider the dominant colours in their riding environment (e.g. coloured foliage and crops, backgrounds associated with sunsets) and choose a colour which will provide contrast accordingly.

The first of these recommendations follows from consideration of the perceptual requirements for judging speed of approach in conditions where only small areas of the horse and rider may be visible or salient to the approaching driver. It is clearly not in the control of horse riders, but is something to be raised by the British Horse Society with relevant highways authorities. It is entirely aligned with the 'safe system' approach currently dominating road safety thinking in Great Britain and across the world.

The second and third of these recommendations are based on the work reviewed on horses, pedestrians, cyclists and motorcyclists. In the absence of legislation covering safety equipment for horses, these recommendations are under the control of horse riders and organisations. The prioritisation of lighting over bright clothing (if only one can be used) is commensurate with findings and theory in all these domains.

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[8] There is some weak evidence that horses of broken colour may be easier for drivers to detect than those of solid colour. This unofficial 'fourth recommendation' should be seen as subordinate to the main three however.

[9] Clothing should ideally meet standards EN1150 or EN471, and should ideally be kept clean.

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Appendix A Calculations relating to judgement of approach

Despite the fact that a horse with rider is a relatively large visual feature on a carriageway (and many road users may express surprise that anyone could fail to notice a horse) there are two factors to consider that mean that detection and judgement of approach may be lower than might be assumed.

1. *Vertical vs Horizontal size*: The visual outline of a horse and rider may be >2.4m vertically which is as high as some commercial vehicles, although a child on a pony may be <2m. There is ample evidence that commercial vehicles, such as trucks or buses are easier to detect and judge than small cars or motorcycles. However there is also some evidence (Gould et al, 2012a) that horizontal extent is a more important factor than vertical extent when judging approach. There is actually a paucity of clear evidence on this difference and no theoretic model. Gould et al (2012a) ran trials with additional lights on motorcyclists to aid judgement of speed at night and there was a significant benefit of a horizontally spaced arrangement, but the same benefit was not gained for an equivalent vertical arrangement. The width of a horse and rider may only be 0.5-0.6m which is quite similar to a modern motorcycle, where we know there is a relatively high incidence of detection errors and an overestimation of the time available before time to contact, relative to estimates given for larger vehicles[10].
2. *Central and peripheral visual processing*: Visual acuity is highest in the ~5deg of the fovea (the area of the eye with high visual acuity). As stimuli become more peripheral to central vision then detection rates of both static and moving images decline. We can assume that if the driver is attending to the road they are looking at the road surface, or another vehicle some 3-5secs ahead. There could be a factor that a reflective vest worn by the rider, who is above the seated eye-height of the driver, becomes more peripheral as the driver approaches the horse. But calculating this for typical scenarios suggest that vertically placed features are unlikely to move out of the central visual field into the periphery. For example, for a driver approaching at 60mph, looking 4secs ahead, the bib of a rider on a horse 300m ahead would be ~0.9deg above the centre of the fovea. By the time the driver has approached to within 4secs of the horse the centre of the bib would have moved to 1.1deg above the central line of sight, but still within an area of high acuity. For a driver with a higher seating position in a commercial vehicle these figures scale differentially but still stay within what we can consider as central vision. So there is little to suggest that a riders bib may become peripheral to a driver's vertical point of gaze towards the roadway. A similar set of results can be derived for the horizontal optical motion of the horse as a fast moving driver approaches. If the driver maintains their point of gaze within their lane then the image of the horse and rider

[10] The high potential approach speed of motorcycles can be a contributing factor. But these errors can occur with a static driver waiting to pull out at a junction, looking down the road at a motorcycle approaching at maybe 60mph. It can be shown that there is very little optical difference, in the horizontal expansion rates, between that scenario and a driver travelling on a country road at 60mph approaching a horse and rider.

should stay within 0.5-0.6deg of the centre of the fovea as the driver approaches from 300m-100m away. Where 'peripheral processing' may become a factor is if/when the driver directs their gaze to the centre of the oncoming lane, because they intend to execute a passing manoeuvre. In this case a horse 100m ahead starts to move towards 1.9deg from the centre of the fovea and if gaze is maintained within the oncoming lane, then the image of the horse and rider will move into peripheral visual field from this point onwards.

Throughout the report we have used the term detection to refer to the state where an observer has noticed the presence of a feature, such as a road hazard, or in this case, a horse. That inner state of awareness is related to conspicuity, which in turn may be related to measurable quantities such as luminance, colour and contrast relative to the background (this may also include motion). As noted previously, detection is an essential state to achieve, but is not necessarily sufficient when approaching other slower moving road users. To pass a horse or cyclist, a cautious and considerate driver should slow, cross the white line of a two-way road and use some of the oncoming carriageway to pass. That act of slowing and the passing manoeuvre both require judgement of the rate of approach. After detecting a horse even a considerate driver following exactly the advice given in the BHS 'Dead? Or Dead Slow?' campaign[11] can look at their speedometer and say, "I'm doing 60, there is a horse ahead, so I'll drop to 15mph". But that doesn't inform the driver as to how long they have to effect that deceleration, or when it would be appropriate to start to move into the oncoming lane if it is free of traffic. The example was given earlier that a driver deciding to slow from 60mph to a slower speed such as 15mph requires information as to how long they have to effect that deceleration, or when it would be appropriate to start to move into the oncoming lane. In principle that could be accurately estimated if the driver knew the precise distance to the horse (e.g. in metres), could mentally convert the indicative mph to m/s and divide the two, although to effect a safe manoeuvre the driver would also need to estimate the speed of any approaching vehicle in the oncoming lane. In practice we know that humans, and most animals, do not have the capability to sense distance directly, the exceptions being those with sensing systems such as echolocation. Human judgments of absolute distance are notoriously difficult beyond ~10m (where binocular differences become very small) and while we are good at detecting changes in relative speed, our judgments of absolute/actual speed are also very poor (Tresilian, Mon-Williams & Kelly, 1999). Fortunately there is an optical short-cut to judging arrival time; provided the driver has an estimate of the optical size of an object/hazard, then if they can also estimate the rate of expansion of the object then the ratio of the two can also give an estimate of time to arrival. This is a much simpler solution for any neural system because the optical size is the patch that the object projects onto the back of the retina, and its expansion is the rate at which it is increasing in size on the retina, which from here on we will call 'looming'. So whereas a radar system may bounce a beam to estimate distance and its rate of change (speed), most animal systems use the light rays that bounce off an object and arrive at their visual system to detect optical size and its rate of change to then estimate how much time they have to initiate an avoidance action. This has been demonstrated in a

[11] http://www.bhs.org.uk/safety-and-accidents/dead-slow - retrieved 04/09/2017

range of animals. The uncanny ability of pigeons to fly out of the path of a car at the last moment, for example, appears to be because they have a neural cluster (the nucleus rotundus) that responds to looming and fires ~1sec before the arrival of an object. The criticality of looming to human collision judgments then raises a set of issues for road safety, particularly in low light conditions.

A.1.1 Looming rates in road scenes

To make an accurate judgement of time to arrival at an object/hazard, the driver needs to detect and then discriminate the rate of looming of that object. The rate of looming ($\dot{\theta}(t)$) is directly related to the size of the vehicle/horse/cyclist being approached *(S)* times the forward speed *(v)* divided by the square of its distance *(z)* using a small angles approximation to simplify the trigonometry. It is useful to note that Equation 1 describes the optical geometry for either: a static observer such as a pedestrian or driver at a junction, observing an approaching vehicle, in which case *v(t)* and *z(t)* refer to the speed and distance of the approaching vehicle; or equivalently a driver travelling forwards but trying to judge the time at which they will reach and pass an horse or cyclist, in which case *z(t)* is the approach distance and *v(t)* the speed of closure. This equivalence is important because we can use findings from studies using static observer scenarios, such as junctions, to inform predictions for moving observer situations.

$$\dot{\theta}(t) \approx \frac{S \times v(t)}{z^2(t)} \quad \text{(Equation 1)}$$

A non-specialist explanation of Equation 1 is that objects that are being approached faster will loom at a higher rate than for slower approaches at the same distance, and when distance is reduced (*z(t)*) looming will also increase. Also, due to the scaling effect of S, large objects loom at a higher rate for a given distance and speed. For the horse and rider scenario, that would seem to provide a good “safety margin” because horses are quite large, if a driver is approaching quickly (e.g. around 60mph) then the rate of looming should rise above perceptual threshold quite early, which should result in the considerate driver slowing down to control the rate at which the observed horse is looming towards them. Also as the distance reduces the $z^2(t)$ term also starts to increase looming which should cause the driver to slow more in response to it. But our recent research has demonstrated that unfortunately this “safety margin” may be illusory (Wann, Poulter & Purcell, 2011). The issue is that although a faster and/or closer object will loom at a higher rate, it is also closer in time, and when it is detected (and its approach judged) it may already be too late to safely complete the action that the observer intended. For a driver travelling on a rural road at 60mph and detecting a horse and rider, what is critical is that the driver initiates deceleration sufficiently early in *time*, to effect a cautious approach. If they also observe that they could use the oncoming carriageway to pass, then they need to judge they have sufficient time to complete that action, to avoid having to accelerate when passing or pull back in sharply due to oncoming traffic. We can re-arrange Equation 1 to substitute time for distance (z) which gives us Equation 2a. In this case we use T_a as a reference for the time the observer needs to complete an action. So a driver may decelerate smoothly from 60mph to, say, 20mph over 4secs (4.44m/s^2) or need >5secs to pass a horse at 20mph (5secs would allow ~45m to pull out, pass and pull back in without accelerating). With Equation 2a we are asking the following: As we approach the last time-point at which the observer could initiate their braking action or manoeuvre (T_a) how does looming vary with approach speed (v), and size of the observed vehicle/cyclist/horse (S)?

$$\dot{\theta}(t) \approx \frac{S}{v(t) \times {T_a}^2} : \quad \text{Eq. 2a} \qquad \dot{\propto}\,(t) \approx \frac{H}{v(t) \times {T_a}^2} \quad \text{Eq. 2b}$$

A critical feature of Equation 2a is that the process of substituting for *z(t),* moves speed *v(t)* to the divisor. What that means is that, completely contrary to our assumption from Equation 1, if the observer is looking for a time gap to complete an action (T_a), then as the time available approaches the limit of T_a, the faster the vehicle approach speed the LOWER the rate of looming (since for higher speeds and the same time available, the approached object will be further away in distance, and therefore smaller on the retina).

A.1.2 Onset of braking

Given Equation 2a, let us re-consider the issue of a driver approaching a horse at either 60mph or 40mph, assuming the horse is moving slowly. This driver typically would brake at ~4.4m/s^2 (equivalent to 0.45g which has been used as a threshold for hard braking, see Simons-Morton et al., 2009) so if they are travelling at 60mph they should start their braking >4sec from the horse. If the driver is travelling at 40mph the reduction to 20mph will only take 2secs at the same braking rate so they could delay braking until ~3secs. But at 60mph, when the driver is 4secs away they will be at a distance of ~107m and the image of the horse will have a horizontal looming rate of ~0.08 deg/s. If the driver is approaching at 40mph when they are 4secs away they will be at a distance of ~71m and the horse will have a horizontal looming rate of ~0.12 deg/s (using either Equation 1 or 2a)[12]. So at the same time point before arrival the image of the horse is looming faster for the *slower* driver. By the time that the 40mph driver reaches the 3sec point then the looming will have risen further to ~0.21deg/s. The durations mentioned here of 4secs and 3secs may seem too short for a cautious approach to a horse, but it is important to note that these are the judged arrival times when the driver is still at 60mph or 40mph, and don't allow for the subsequent effect of deceleration. If a driver at 60mph initiates a 0.45g deceleration when they perceive they are 4secs away, then after 2secs they have reduced their speed to 40mph, their distance is 62.7m, and their arrival time at that speed and distance is 3.52secs (even through 2secs have elapsed). By the time they have been braking for 4secs, they would be at 20mph, their distance behind the horse would be 36.4m and at that speed and distance their arrival time would be 4.1sec, so by reducing speed they have regained their original time window of 4secs in which to execute the next action.

Using Equation 2a we have a set of 'predictable errors' which are:

III. When drivers are travelling faster, they are more likely to fail to notice that it is time to initiate their braking action in order to slow to a cautious speed before they get to

[12] Equation 2b is included to illustrate that the same effect of speed is evident for other motion cues such as changing height in the scene (H), whereby the rate of contraction of the height in the scene, which could also be used to guide arrival time, is also lower for faster approaching vehicles if the observer is looking for a specific time gap to execute an action.

within 40-50m of a horse. This may result in late braking or inadequate braking on approaching a horse and rider.

IV. When the object being approached has a smaller area that is visible at a distance then the errors highlighted above will scale upwards. As *S* (Equations 1, 2) decreases then the looming rate decreases and errors are more likely to occur.

A.1.3 Remedial measures

Although a horse and rider is a large visual feature and should be conspicuous, there may be settings such as low light conditions or environmental conditions (such as large trees and patterns of light and shade) that may mean a horse and rider is not readily detected by a driver approaching at speed. The speed of approach of a driver is a critical factor as discussed above, because this means that the distance at which a driver would ideally detect the horse and rider, and then judge the rate of approach, becomes farther with increasing speed. As a consequence the optical size of the horse, which is crucial for detection, becomes smaller, and the rate of looming which is critical for estimating the rate of approach is reduced at higher speeds (Equation 2a). This leads to a first option for risk reduction:

1. There is a case for lobbying regional and national authorities for reduced speed limits on rural roads where there is significant horse and rider activity, such as areas where there is a high density of stables. Accident statistics would help this argument, but registered statistics do not capture the ‘everyday’ cases of startled horses that could have resulted in a major accident, but didn’t. BHS’s self-reported statistics may help in understanding near misses. The optical geometry alone argues that it is unwise to have drivers travelling at 60mph on roads that are routinely and regularly used by horse riders.

The sample looming figures generated above of ~0.08deg/s for a driver approaching at 60mph are above the thresholds that have been found in experimental work. In lab-based work thresholds have been reported as low as 0.02deg/s (lower threshold = higher sensitivity), but that is unlikely to be detected in complex natural scenes. Work on driving has cited thresholds in the range of 0.08deg/s and our own work has suggested ~0.06deg/s if the stimuli is presented to the fovea, but poorer sensitivity of up to 0.2deg/s if the stimuli is 5deg outside of the fovea. In respect to the latter figure we should consider the issue raised in the initial discussion in this section, that in some cases a driver may be predominantly attending to the oncoming lane and oncoming traffic to see if they are able to pass the horse, so the image of the horse and rider may be in their peripheral field. Averted gaze will lead to lower sensitivity and looming rates may need to rise above 0.1deg/s to be above threshold for detection of looming. But there is another major factor to consider, the looming rates calculated previous were based on the assumption that the driver could accurately perceive the full outline of the horse’s flanks from >100m, so S was set at 0.6m. That may not always be the case; part of the flank may be in shadow, or perhaps the most salient feature might be the coloured vest of the rider in which case S may be half that value, which in turn would reduce the looming rate by half to ~0.04deg/s which does start to fall below measured thresholds. This emphasizes that it is not just ‘visibility’ that is important, but the spatial extent that is visible. As a simple example, a single, high luminance rear light, as used by many cyclists, is conspicuous in the dark but is too small in visual area to allow for accurate approach judgments. To aid not only detection, but judgement of approach, a single light is best supplemented by the cyclist wearing distributed reflective material which will be picked out in the car headlights. Simulations and field trials have demonstrated that changing the lighting pattern for motorcycles, to include flanking lights so that there is a broader visible area can offset judgment errors by car drivers trying to judge motorcycle approach, particularly at night (Gould et al., 2012b; Helman et al., 2014). This supports the following two recommendations:

2. Riders should consider safety wear that incorporates LED lights. These are not just more effective at ensuring detection when daylight turns to a dull afternoon or early evening, but they are very effective at marking the spatial extent which supports the information for more accurate judgements of approach rate and deceleration by drivers. A suitable array would be two LEDs incorporated into a rider's vest at shoulder width and ideally equivalent LEDs at each of the side of the horse's flank, so they are separated by ~0.6m. The spatial displacement should have considerable advantages over using only products that add illumination to the horse's tail, which should aid detection but is unlikely to help with discrimination of speed of approach.
3. Riders should use bright safety materials wherever feasible. The simplest versions are rider vests although because of the issue of spatial extent it is optimal to have these displayed across the largest horizontal extent that is possible. Adding a high-visibility component to a winter blanket that covers the rear of the horse would be optimal. For reasons we don't fully understand the vertical extent seems to be less effective. Reflective materials tend to be incorporated into high visibility wear at little additional cost, but as discussed these are only likely to add significant benefits in very low light conditions and when vehicle headlights fall on them. Riders should assess their common riding environment if there are high visibility colour options.

Conspicuity of horses and riders on roads

The literature on visibility and conspicuity was reviewed, in order that the best advice for horse riders could be provided with the aim of increasing their safety (and that of their mounts) when riding on public roads. The main scenario considered was that which occurs when riders are approached by motor vehicles from behind, often at speed. Research with horses and with other vulnerable road user groups (pedestrians, cyclists, and motorcyclists) was included, and knowledge regarding the human visual system, in relation to object detection and judgement of approach, was considered. Three recommendations were made. First, speed limits on national speed limit roads with frequent equestrian activity should be reduced. Second, riders should choose to wear lights wherever possible, ideally in a pattern that highlights their width (lights on their shoulders and the flanks of their horse, for example). Third, in the absence of lights, riders should wear high visibility and reflective clothing, choosing a colour appropriate for their riding environment.

Other titles from this subject area

PPR662 Helman, S., Palmer, M., Haines, C. and Reeves, C. (2014). The effect of two novel lighting configurations on the conspicuity of motorcycles: a roadside observation study in New Zealand. Published Project Report (PPR682). Crowthorne: Transport Research Laboratory.

PPR638 Helman, S., Weare, A., Palmer, M., and Fernandéz-Medina, K. (2012). Literature review of interventions to improve the conspicuity of motorcyclists and help avoid 'looked but failed to see' accidents. Published Project Report (PPR638). Crowthorne: Transport Research Laboratory.

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