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Literature review of interventions to improve the conspicuity of motorcyclists and help avoid 'looked but failed to see' accidents

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Executive summary

Background

Road collisions involving motorcyclists continue to represent a serious public health concern, both in New Zealand and worldwide. For example in New Zealand, the official road casualty statistics published by the New Zealand Ministry of Transport (NZ Ministry of Transport, 2011a) showed that in 2010, 50 motorcyclists died and 1,300 were injured in road collisions, representing 13% of deaths and 9% of injuries on the road despite motorcycles representing only approximately 3.5% of registered vehicles.

It is widely accepted around the world that one key factor in motorcyclist crashes is the difficulty other road users have in detecting an approaching motorcyclist or correctly appraising their speed and position. This is of particular concern at road intersections, where drivers need to detect gaps in oncoming traffic to make turns either across or into traffic flows. If a motorcyclist is not detected by a car driver in this situation (so-called 'looked but failed to see') then this can lead to a manoeuvre that violates the motorcyclist's path, and a potential crash. As a result, for decades there have been calls from road safety campaigners and policy makers for improvements to the conspicuity of motorcyclists to help reduce the number of such accidents.

In order to gain a better understanding of possible interventions that might be utilised in New Zealand to improve motorcyclist safety, the Motorcycle Safety Advisory Council (MSAC) commissioned TRL and RTI to carry out a review of the international literature addressing the effectiveness of interventions that are designed to increase motorcyclist conspicuity and visibility. This is intended to help MSAC in making evidence-based decisions as to how funding from the Motorcycle Safety Levy can best be invested in practical interventions to increase the visibility and conspicuity of motorcyclists in New Zealand.

Conspicuity and 'looked but failed to see' accidents

In this report, first the terms 'conspicuity' and 'looked but failed to see' are discussed.

It is noted that there are at least three terms commonly referred to as conspicuity, these being:

- Visibility – the extent to which an object stands out from its surroundings when observers are aware of its location.
- Search conspicuity – the extent to which an object stands out from its surroundings when observers are searching for it within a scene.
- Attention conspicuity – the extent to which an object stands out from its surroundings when observers are viewing the scene, but not searching deliberately for the object.

It is also noted that the term 'looked but failed to see' does not adequately describe all of the cognitive or perceptual failures that can occur when a motorist executes a manoeuvre at a junction and violates a motorcyclist's path. Specifically:

- Sometimes drivers simply do not look at all when pulling out of a junction – this is not a conspicuity issue.

- Sometimes drivers look, but they do not do so for long enough or in the correct places within the scene – measures that increase attention conspicuity should be useful in avoiding this failure.
- Sometimes drivers look adequately, but they still fail to detect an oncoming motorcyclist – measures that that increase search conspicuity should be useful in avoiding this failure.
- Sometimes drivers look and detect an oncoming motorcyclist, but fail to assess its 'time to collision' correctly – measures that provide a greater amount of visual information on which drivers can base their estimates of time to contact should be useful in avoiding this failure.

The review

A review using a systematic methodology for searching, inclusion, and assessing quality was conducted on the published literature in the TRID database (a combination of the Transport Research Information Services [TRIS] and International Transport Research Documentation [ITRD] Databases).

The search returned 331 potentially relevant papers (based on keywords, titles and abstracts). These papers were then assessed against inclusion criteria. To be included papers needed to:

- Be related to measures intended to improve motorcyclists' visibility or conspicuity (or intended to improve the accuracy of judgements of motorcyclists' speed or time to contact by other road users)
- Involve either collection of data, or the analysis of existing datasets (i.e. be based on evidence rather than speculation or opinion)
- Involve treatment(s) or experimental manipulation(s) of some kind (i.e. the impact of an intervention or experimental condition on the outcome measure)

In total 95 papers were deemed relevant and were subjected to a full-text review to assess their scientific quality. Of these, 27 were deemed to be of high enough scientific quality for inclusion in the final review.

This systematic methodology ensured that, as far as possible, any conclusions drawn from the review were based on the most relevant and best available evidence.

Findings

The majority of early evidence (mainly from the 1970s and 1980s) concerned bright clothing and daytime running lights on motorcycles. When considering the weight of evidence, both seem to be capable of improving conspicuity, when this is measured in terms of detection (under search and attention conspicuity conditions), and when measured in terms of a behavioural response (such as size of gap accepted in front of a given motorcycle). The majority of studies covered in this review support this conclusion, although there are limitations as to how effective any individual interventions can be due to the number of different visual contexts in which motorcyclists find themselves when riding. For example, coloured clothing is more effective when viewed against a contrasting background. In terms of lighting, although it appears that dedicated daytime lighting on motorcycles is effective in increasing conspicuity, this effect may be smaller when other vehicles have their lights on. More research may be needed on this specific issue, however, especially in terms of understanding its impact on other accident types.

When lighting is arranged in such a way as to accentuate the form of the motorcycle (and to provide greater information for judging approach speed), this aids the observer in determining the time to arrival of the approaching bike (especially at night). However, little real-world research has been done on this specific type of intervention.

Across all treatments there is evidence that colour can play a role in effectiveness; this may be especially true in settings where coloured motorcycle lights aid in the motorcycle standing out from surrounding vehicles which have white lights.

Although most studies reviewed show benefits of bright clothing, dark clothing may be better if the background is also brightly coloured. In line with the underlying mechanisms proposed, higher contrast with background surroundings to enable better visibility, search conspicuity, and attention conspicuity would be beneficial. Given that environments may differ over even fairly small changes in time or location, there is not likely to be a one-size-fits-all solution, meaning that motorcyclists need to be aware of the limitations of whichever interventions they use.

The New Zealand context

With any road safety intervention, it is desirable to bring benefits to as many people, in as many situations, as possible. However there are necessary limitations, not least because interventions will tend not to have ubiquitous effects; rather, they will work better in some situations than in others. Bearing this in mind, a brief analysis of New Zealand accident data was carried out to establish if any prioritisation of crash scenarios by interventions might be possible.

Official casualty data from New Zealand in 2010 showed that there were nearly twice as many fatal junction crashes involving motorcycles on rural roads as there were on urban ones (11 versus 6). However, there were more than six times as many serious and slight injury accidents involving motorcyclists at urban junctions as there were at rural ones (158 versus 24, and 307 versus 48 respectively). This means there are nearly six times as many such crashes at urban junctions as at rural ones. Using the average social costs per reported crash (adjusted for non-reporting) in New Zealand (NZ Ministry of Transport, 2011b) this means that accidents at urban junctions have a combined social cost around two and a half times as high as those at rural junctions.

Combining these data, our recommendation is that, if the focus of interventions is to be on achieving the best possible return in terms of savings in social costs, targeting urban junction accidents would be sensible. If the focus is to be on reducing fatal accidents, then targeting rural locations would be preferred although it should be noted that, in statistical terms, the numbers of fatal accidents are small and are likely to be subject to wide variation on a year by year basis.

Recommendation 1 – validation study on lighting configurations

In terms of validation activities in New Zealand to gain a better estimate of the likely impact and acceptability of different interventions to New Zealand motorcyclists, the most promising intervention type (and the one on which there is least work in real-world settings) would appear to be physical changes to motorcycle lighting. These could be configurations that lead to greater contrast with the background (especially differentiation of motorcycles from surrounding traffic with lights – for example differently coloured lights that stand out from the white lights typically see on cars). Alternatively they could utilise additional lights to increase the visual 'surface area' of the bike and therefore help not only with detection but also with time-to-collision estimation. Such interventions also have the benefit of being preferable to high visibility and reflective clothing to motorcyclists (based on the small amount of work done on this topic) meaning that such interventions are more likely to be used by motorcyclists, and thus have a chance to be effective.

The scope and design of such a validation activity will depend on the resources and time MSAC has available to carry out such work, and on other factors such as whether there is any intention in New Zealand to introduce any specific legislation relating to or impacting on motorcycle conspicuity. For example, if any changes are planned to laws relating to car daytime running lights, this would need to be accounted for in any validation work. Recent changes to priority movements at junctions in New Zealand would also need to be addressed in any study examining changes over time in collision rates.

For the current purpose of recommending some validation activity focused on lighting configuration changes, we define three possible studies that could be run using different outcome variables, depending on the scale of adoption anticipated by MSAC in the motorcycling population. These three possible studies are described in Table 6-2.

Whatever its scope or design, the validation work should also take into account the response of motorcyclists to the interventions and, in the case of analyses on ongoing accident data, the prevalence of their use at trial sites.

Recommendation 2 – raise awareness of potential (and limitations) of high visibility and reflective clothing

We do not feel that further validation work is needed to establish the usefulness of high visibility and reflective clothing. As a general principle, MSAC should continue to encourage riders to wear clothing that is inherently highly visible, reflective if possible, and clean, when riding. If awareness campaigns are used to this end they should focus on two things. Firstly, riders should be encouraged to wear bright and reflective clothing by default, on the grounds that this will often make them more visible to other road users. Secondly, riders should be made aware of the inherent limitations of any aid to visibility or conspicuity; special attention should be paid to making riders aware that there is no 'one-size fits all' solution (for example because of different contrasts with backgrounds) and that, even if they have been seen by a car driver waiting at a junction, this does not mean that the car driver will have appraised their approach speed accurately (especially at night).

Abstract

Road collisions involving motorcyclists continue to represent a serious public health concern worldwide, including in New Zealand. It is widely accepted that one key factor in motorcyclist crashes around the world is the difficulty other road users have in detecting an approaching motorcyclist or correctly appraising their speed and position (typically at junctions). The Motorcycle Safety Advisory Council commissioned TRL to review the international literature on motorcycle conspicuity, to establish those treatments that might be most suitable for use or further validation work in New Zealand. The review used a systematic methodology for searching, inclusion, and assessing the quality of studies of treatments designed to improve motorcyclist conspicuity. The review concluded that, even when considering only the best quality studies, it has generally been shown that high visibility and reflective clothing, and headlights or daytime running lights on motorcycles, have been effective in increasing motorcyclist conspicuity. In addition, novel lighting configurations can be effective (especially at night), if for example they are designed to make motorcycles 'stand out' against other vehicles with lights, or to accentuate the visual profile of motorcycles and provide drivers with more visual information to judge time to arrival. There are limitations to all interventions, not least because conspicuity typically depends on a high visual contrast with the background, and this can vary from situation to situation. The review recommends that validation work on novel lighting configurations is defined and then taken forward in New Zealand, and that work continues to raise awareness among bikers as to the benefits (and limitations) of high visibility and reflective clothing.

1 Introduction

1.1 Motorcycle safety and public health

Road collisions[1] involving motorcyclists continue to represent a serious public health concern, in New Zealand and world-wide. For example, crash statistics for the year ended 31 December 2010 published by the New Zealand Ministry of Transport (NZ Ministry of Transport, 2011a) showed that 50 motorcyclists died and 1,300 were injured in road collisions, representing 13% of deaths and 9% of injuries on the road despite motorcycles only representing around 3.5% of registered vehicles. The New Zealand Household Travel Survey shows that on average the risk of being in a collision in which someone is injured or killed is 23 times higher for a motorcyclist than for a car driver, keeping distance travelled constant (NZ Ministry of Transport, 2011a).

Similar estimates of the relative risk for motorcyclists are found around the world, and it is far from controversial to say that motorcycling is the most risky form of mainstream transport per kilometre travelled.

1.2 The problem of conspicuity

It is widely accepted that one key factor in motorcyclist crashes around the world is the difficulty other road users have in detecting an approaching motorcyclist or correctly appraising their speed and position. This is of particular concern at road intersections, when drivers need to detect gaps in oncoming traffic to make turns either across or into traffic flows. If a motorcyclist is not detected by a car driver in this situation then this can lead to a manoeuvre that violates the motorcyclist's path, and a potential crash. Studies from around the world have confirmed that these so-called 'looked but failed to see' (LBFTS) accidents are a particular problem for motorcyclists (e.g. Herslund & Jørgensen, 2003). The collision data from New Zealand are compatible with this interpretation; intersection collisions make up 37% of injury accidents involving motorcyclists, which is the largest single category (NZ Ministry of Transport, 2011a). In addition, in nearly 80% of these crashes, the other road user (usually a car driver) is held to have primary responsibility.

In light of this, a number of researchers have called for improvements to be made to the conspicuity of motorcycles and motorcyclists, in order than they might be more easily seen by other road users (e.g. Williams & Hoffman, 1979; Olson, Hallstead-Nussloch & Sivak, 1981; Hole, Tyrrell & Langham, 1996; Rößger, Hagen, Krzywinski & Schlag, 2011). Others have also pointed out that in addition to measures to improve the extent to which motorcyclists are detected, measures to improve drivers' appraisals of motorcyclists' speed and time-to-arrival might also help to reduce LBFTS accidents (see for example Gould, Poulter, Helman & Wann, 2012).

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[1] There are strongly held views in the road safety literature for and against the use of terms such as 'accident', 'collision' and 'crash'. For those interested in this debate we refer you to Davies and Pless (2001), Elvik and Vaa, (2004), and McKenna, (2007). In this report we have chosen to use all these terms interchangeably.

1.3 This review

In order to gain a better understanding of possible interventions that might be utilised in New Zealand to improve motorcyclist safety, The Motorcycle Safety Advisory Council (MSAC) commissioned TRL and RTI to carry out a review of the international literature addressing the effectiveness of interventions that are designed to increase motorcyclist conspicuity and visibility.

This is intended as the first step in enabling MSAC to make evidence-based decisions as to how funding from the Motorcycle Safety Levy can best be invested into practical interventions to increase the visibility and conspicuity of motorcyclists in New Zealand.

The literature on motorcyclist conspicuity is known to be substantial, and comprises a wide range of empirical and theoretical papers, in addition to editorial and media pieces on the issue. In other fields dealing with public health outcomes, systematic reviews of empirical evidence (such as those carried out by the Cochrane Collaboration – see www.cochrane.org) have been accepted as being the best way to establish the level of support for any given intervention. Therefore this is the approach we take here. Studies that have sought to examine the effectiveness of interventions to increase the conspicuity of motorcycles or motorcyclists (in lab studies, or in real world settings) were reviewed using a systematic approach to ensure that only relevant studies were included. In addition, studies were graded for scientific quality to ensure that any conclusions drawn were based on the best available evidence.

The evidence is then set in the New Zealand context when making recommendations.

1.4 Structure of this report

The remainder of this report is structured as follows.

- Section 2 gives a brief history of motorcycle conspicuity to set the context for the review.
- Section 3 discusses the issue of conspicuity from the psychological perspective, and sets out how the concept is related to LBFTS accidents.
- Section 4 describes in detail the review methodology, including those criteria used for inclusion of studies in the review, and those criteria used to grade studies for scientific quality.
- Section 5 presents the key findings.
- Section 6 discusses the findings from the New Zealand and motorcycling perspectives, and makes recommendations.

2 A brief history of motorcycle conspicuity

> "*In late 1975 reports of accidents indicated that casualties associated with powered two-wheeler vehicles were on the increase. This rise was sufficiently large to negate the declining trend in total accidents experienced in previous years. Motorcycling as a mode of transport was rising in popularity; bringing with it a rise of 20 per cent in casualties. On this evidence the Greater London Road Safety Unit chose this topic for their annual publicity campaign. Detailed analysis of data indicated that a major factor in motorcycling accidents was a failure of other drivers to observe these vehicles in the general street scene*" (Lalani and Holden, 1978, p4)

The 1976 Greater London 'Right Bright' campaign may have been the first road safety campaign specifically designed to encourage riders of powered two-wheelers to improve their conspicuity by wearing bright clothing, preferably of fluorescent material, and by switching on their headlights in daytime. The campaign was extensive, running from August to October 1978, and involved radio advertising (on two London-based stations in the UK), a poster campaign, leaflets distributed through a number of routes (including dealers, garages, colleges, businesses and by London's Metropolitan Police Service) and give-away items such as combs, pens and key-rings.

Subsequent observations made from the roadside found statistically significant changes in the numbers of riders using conspicuous clothing and headlamps during daytime. These results may have been aided by a second campaign launched by the London Accident Prevention Council in April 1977, and other similar efforts. One of the authors of this report (Palmer) recalls attending a large motorcycle event during the summer of 1977 at which the 'daytime headlamps' message was being publicised. Subsequently, he recalls being told by drivers "Your headlight's on!"; they looked confused when told it was supposed to be.

Another notable early research project in motorcycle safety was that of Hurt, Oullet and Thom (1981). During a 24 month period in 1976 and 1977 a team of researchers investigated 900 motorcycle collisions and 3,600 traffic accident reports in the Los Angeles area. They also returned to over 500 crash scenes on the same days of the week and time of day, and under the same environmental conditions, so that they could conduct interviews with non-crash-involved riders at these scenes, enabling comparisons to be drawn between the two groups. The study generated a large number of findings related to accident characteristics, helmets, journey types and other factors such as alcohol involvement in crashes. One key finding was that around two thirds of crashes between motorcycles and cars involved car drivers failing to see a motorcyclist and violating their right of way. Others were that the use of daytime headlamps or the wearing of high-visibility jackets appeared to reduce collision involvement, and that conspicuity was especially important on motorcyclists' frontal surfaces (because of the importance of being seen when approaching intersections).

In the light of such findings, further research was carried out into collisions where a driver violates a motorcyclist's right of way, and the development of countermeasures intended to reduce the incidence of such accidents. At this time, the range of conspicuity aids available to riders was limited; typically headlamps or a fluorescent waistcoat were the only options. It is worth noting that headlamps fitted to motorcycles at this time would usually have a 30W or 35W dipped beam and be tungsten, rather than the 55W halogen as is standard today; smaller motorcycles and mopeds would usually have had lamps of smaller diameter, and be lower-power, all of which would be expected to have an impact on their effectiveness as aids to conspicuity. This was acknowledged by Watson (1979) who reported on the development of the UK Transport and Road Research Laboratory's Experimental Safety Motorcycle 1 (ESM1 – see Figure 2-1); ESM1 had a pair of daytime running lamps (DRLs) which although only 18W, were fitted with a lens with gave a high degree of light scatter designed to attract attention to the motorcycle. Another feature of ESM1 was that it was fitted with weather shields in front of the rider's legs, with the shields painted white to further improve conspicuity on the frontal surface; it was rare at that time for motorcycles in everyday use to have such features as fairings or leg shields.

Figure 2-1: TRL Experimental Safety Motorcycle 1 (Watson, 1979)

The Motorcyclists Handbook (Minton 1981) gives an example of how information for riders was developing, with riders being advised to make themselves conspicuous, mentioning items such as fluorescent sash/belt and a brightly-coloured jacket.

Motorcyclists had adopted their own acronym for being the victim of a crash where a driver had emerged in front of them: 'SMIDSY', from the phrase commonly used by the at-fault driver: "Sorry, mate, I didn't see you". The phrase had entered the riders' vocabulary so successfully that when, in 1982, the UK's BBC produced a television series and accompanying book they used the phrase for their titles.

Figure 2-2 and Figure 2-3 show additional examples of early approaches to improving the conspicuity of motorcyclists, both in the UK.

Figure 2-2: UK Police motorcycle with single DRL

Figure 2-3: Motorcyclists wearing fluorescent tabards; note how second rider's tabard is obscured by the motorcycle's fairing and screen

As research progressed, it became apparent that increasing the conspicuity of motorcyclists using lighting and clothing interventions was possible, but not a trivial undertaking. For example Donne and Fulton (1985), who examined a wide range of lighting solutions including varying power, size and numbers of headlamps cautioned that "The level and significance of the benefits afforded by conspicuity aids varied between the sites at which they were tested…It is not possible, on the basis of the work described, to recommend the use of a single aid to conspicuity which might be expected to be effective in all circumstances…the use of even…effective aids is by no means a guarantee that a motorcycle will be seen in all circumstances" (Donne & Fulton, 1985, p13).

Significant improvements in motorcycle lighting have taken place since the earlier research, with the introduction of halogen and HID headlamps and the use of light emitting diodes (LED). Rider clothing has also developed; in the early 1980s developments in retro-reflective and fluorescent materials allowed the production of items such as 'Sam Browne' diagonal belts which were fluorescent in daytime and retro-reflective at night. Figure 2-4 shows an example of these developments, again on UK Police riders. However a glance at Figure 2-5 will show that even with modern equipment, Donne and Fulton's point about the context-specificity of such interventions still stands. (The front cover photo on this report provides−quite literally−a contrasting example; the dark clothing of the rider contrasts well with the light background, while the lighter bike fairing is almost camouflaged against the road surface.)

Figure 2-4: UK Police motorcyclists wearing fluorescent and retro-reflective 'H belt' harness

Figure 2-5: Pedestrian with high quality modern high visibility clothing, but note the low contrast against background

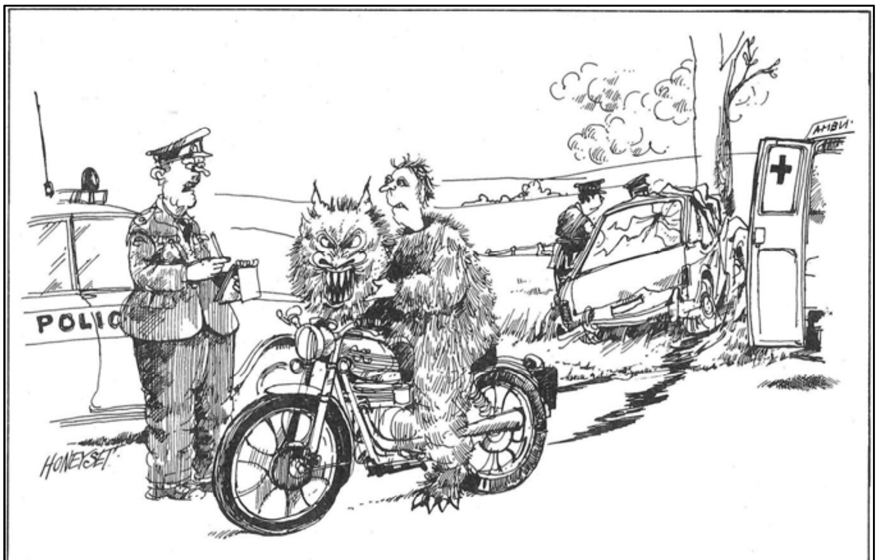
Another development in the field has been an appreciation of the role of aspects of conspicuity other than visibility. For example, Brooks and Guppy (1996) found that car drivers who had relatives who rode a motorcycle were less likely than average to be involved in a collision with a motorcyclist; one suggestion for this effect is that for these drivers, motorcyclists are more 'cognitively conspicuous' (i.e. expected). Recent data from Crundall, Crundall, Clarke and Sharar (2012) are also relevant here; car drivers who also have experience as motorcyclists look in different places for motorcyclists at junctions when compared with other experienced car drivers and with novices. Again the suggested mechanism for this is that their experience as motorcyclists gives them an appreciation of where to look, and this 'cognitive conspicuity' aids detection.

In summary, there is a long history of research into the conspicuity of motorcyclists and motorcycles. Early focus was on simple daytime lights and high-visibility clothing, after conspicuity was revealed as an important factor in several studies in the 1970s. Improvements in lights and clothing technology have clearly had an impact on the field, but road casualty statistics from a number of countries show that LBFTS collisions involving motorcyclists continue to impart a substantial injury burden on society. We now turn our attention to a discussion of conspicuity itself, and the multiple ways in which it may relate to LBFTS accidents.

3 Some definitions – 'conspicuity' and 'looked but failed to see'

The terms 'conspicuity' and 'looked but failed to see' have become ubiquitous in motorcycle safety research. In this section we briefly consider the multiple ways in which they have come to be used, and we define those aspects that are included in this review.

3.1 What does 'conspicuity' actually mean?



"I know it's a good idea for motorcyclists to make themselves conspicuous but this is the third person you've frightened to death this month."

© Martin Honeysett (used with permission)

Lesley (1995, cited in Langham & Moberly, 2003) defines conspicuity as the extent to which an object stands out from its surroundings. Conspicuity is different to visibility (although in practice the same factors affect both) which is usually defined as the ease with which an object can be detected when an observer is aware of its location. It is generally acknowledged that the most important determinant of an object's conspicuity/visibility is its contrast with its surroundings, although other features such as an object's movement relative to its background also play a role (e.g. Rushton, Bradshaw & Warren, 2007). Since the detection of other road users is crucial to avoiding collisions, conspicuity is clearly an important factor in road safety.

A further important distinction is offered by Cole and Hughes (1984) who discuss the difference between 'search' and 'attention' conspicuity. Search conspicuity refers to the ease with which an object is located in the scene when the observer is actively searching for it, while attention conspicuity is the extent to which the object grabs attention even when the observer is not actively trying to locate it. A final relevant concept is that of cognitive conspicuity. This is the extent to which an object is expected by the observer; this is highly relevant to the issue of motorcycle LBFTS accidents as the relative rarity of motorcycles on the road may mean that drivers have an expectation that motorcycles generally will not be present in the road scene, and thus may fail to detect them (see Hancock, Wulf, Thom & Fassanacht, 1990). A related concept is that of 'attentional set' (Most & Astur, 2007), in which people may become used to responding to specific types of stimulus, with stimuli that do not match this 'set' suffering from a slowing of response times when encountered.

Another way of thinking about these definitions is to consider a thought experiment in which we are trying to establish the average distance at which a motorcycle is generally detected by observers. In short:

- If the observers are directed to look *at* the location of the motorcycle to see if they can detect it, we are measuring visibility.
- If the observers are directed to look *for* the motorcycle in the scene but are not told where it is, we are measuring search conspicuity.
- If the observers are simply asked to report the things in the road scene that grab their attention, we are measuring attention conspicuity.

Cognitive conspicuity in this thought experiment would not be measured directly but might be manipulated by using participants more or less familiar with motorcycles or by directly manipulating the number of scenes in which motorcycles are present. The use of participants familiar with motorcycles, or the presence of a greater number of scenes with motorcycles, would both be expected to raise the cognitive conspicuity of motorcycles, and thus would be expected to increase detection distance (for discussion of the familiarity effect see Brooks & Guppy, 1996, Magazzu, Comelli & Marinoni, 2006, Crundall, Humphrey & Clarke, 2008, and Crundall et al., 2012; for discussion of the role expectancy can play in detection see Hole & Tyrell, 1995, and Labbett & Langham, 2006; see also Section 5.1.1 when daytime headlamp legislation is discussed).

3.2 What does 'looked but failed to see' actually mean?

The term 'looked but failed to see' has come to be used to describe collisions (typically at junctions) in which drivers claim not to have seen an oncoming motorcycle that they have then collided with through violation of its forward path[2]. Despite its widespread use, the term does not adequately describe all the potential failures of perception or cognition by a driver who has been involved in such an accident with a motorcycle. Figure 3-1 illustrates that there are at least three of these failures.

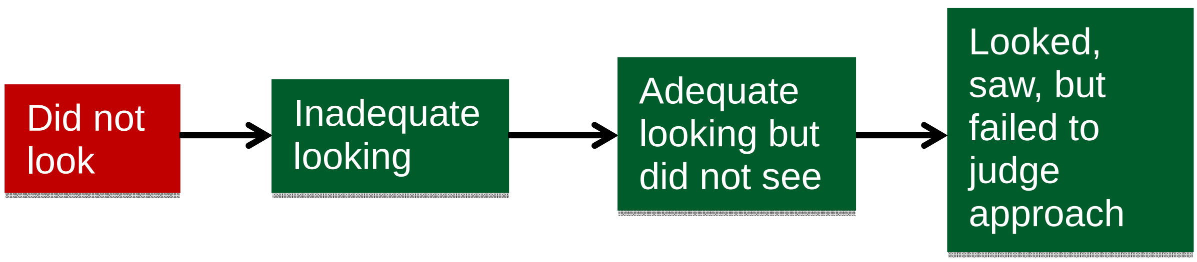


Figure 3-1: 'Looked but failed to see' accidents have a number of potential underlying failures, not all of which are fully captured by the term

The first potential failure is that a driver simply does not look before emerging from a junction, either through negligence or deliberate risk taking. This type of collision clearly

[2] As we shall see later, similar mechanisms may be at play in other accidents with motorcyclists such as rear-end shunts.

cannot be influenced by aids to motorcycle conspicuity, and is therefore outside of the scope of this review.

The second potential failure is that a driver has at least looked in the direction of oncoming traffic, but had failed to look adequately; examples of this could be looking for too short a time to allow coverage of all relevant stimuli, or failing to look in the places where motorcycles may be located. In this case, measures that increase the attention conspicuity (or cognitive conspicuity) of a motorcycle that is present in the scene may help detection (by helping the motorcycle to 'grab attention').

The third potential failure is that a driver looks in the direction of oncoming traffic, for an adequate amount of time and in the correct locations, but still fails to detect a motorcycle that is present. In this case the chance of a driver detecting an oncoming motorcycle may be improved by measures that aim to improve its visibility or search conspicuity (if the driver is looking directly at the motorcycle, or for the motorcycle, respectively)[3].

The fourth failure is not technically a conspicuity issue as defined above, as it assumes that a driver has already detected the motorcycle. However it is potentially highly relevant to LBFTS crashes (see contributory factors data in DfT, 2010). Because of the small size of motorcycles it is difficult for drivers to assess their approach speed and the time which is available for a driver to execute a manoeuvre crossing the motorcyclist's path (see Horswill, Helman, Ardiles & Wann, 2005 for a discussion of the size-arrival illusion and lack of 'looming cues' for smaller approaching objects and how these apply to motorcyclists approaching junctions). This may be a particular issue in night-time collisions (see Pai et al., 2009; Plainis et al., 2006) since bikes tend only to have a single headlamp, which further reduces the information available to driver by which to judge their approach speed (see Gould et al., 2012).

The model outlined in Figure 3.1 is not a complete description of all the failures that can occur in LBFTS accidents; the most obvious extensions to the model would be those of action selection and implementation, which potentially happen even after all the stages above have been carried out successfully but which might themselves be carried out inadequately (for example a poorly executed turn) and lead to a collision. However for the purpose of the scope of this review, the stages identified above outline the most relevant underlying psychological and perceptual processes.

3.3 What is included in this review?

In this review our primary aim was to cover interventions that target the second and third failures in the LBFTS continuum outlined in Figure 3-1. However due to recent research developments relating to the appraisal of oncoming motorcycles, and their potential importance in LBFTS accidents, we also included any references found that covered this issue. In other words we are interested in reviewing interventions that seek

[3] Of course sometimes the lack of detection will be due to the line of sight between the driver and approaching motorcycle being obstructed by roadside objects or other vehicles. Again this is outside of the scope of the current review, and is probably best dealt with through the engineering of junctions to avoid such obscuration, and possibly the training of motorcyclists to avoid such blind-spots (see US Motorcycle Safety Foundation, 1991) or use lane positioning to move through the driver's field of view (see MacKillop, 2006 as cited in Motorcycle Action Group, 2006; Palmer, 2008).

to improve the chances of motorcyclists being detected (visibility or search/attention conspicuity) or the chances that other road users (usually drivers) will accurately judge their approach speed and therefore the time available for manoeuvre. It is important to note that educational and training interventions were defined as out of scope *a priori* by the client organisation. Thus we limit ourselves to interventions that involve some direct manipulation of the appearance of motorcyclists, although we also consider alternative approaches in Section 6 when discussing the next steps that might be taken in understanding the problem.

4 Methodology

The review was intended to encompass as much of the relevant available literature as possible relating to motorcycle conspicuity, visibility and speed judgement (see Section 3). There were three broad stages of the review:

1. Identify potential candidate studies within the literature
2. Filter these to exclude irrelevant studies
3. Conduct the review of the remaining papers

The remaining sub-sections describe in more detail each of these stages.

4.1 Identify potential candidate studies

All potential candidate studies were sourced from TRID (Transport Research Information Services [TRIS] and International Transport Research Documentation [ITRD] Database), which is a newly integrated database that combines the records from TRIS and ITRD providing access to over 940,000 records of transportation research worldwide. A search of TRID was conducted through the TRL library using the following search terms:

(motorcycle OR motorbike OR motorcyclist OR scooter OR moped OR "powered two wheeler" OR PTW OR "two wheeled vehicle") AND (conspicuity OR salience OR visibility OR "high-viz" OR "hi-viz" OR fluorescent OR retroreflective OR reflective OR dayglo OR dayglow OR colour OR color OR perception OR identification OR headlamp OR headlight OR lamp OR light)

This search returned 331 potentially relevant papers for review. Additional papers and background materials were gathered through the experience of the third author as a professional motorcycle trainer, and from personal contacts of the first author.

4.2 Filter to exclude irrelevant studies

Due to the large number of studies returned by the search the filtering was split into two stages. The first was a review of the abstracts, and the second was a more thorough review of the full-text versions of those references making it through the first pass.

4.2.1 First-pass abstract review

The first pass was conducted based on the abstracts alone, in which researchers scored each paper against the three absolute criteria for inclusion in the study:

1. The paper must be related to measures intended to improve motorcyclists' visibility or conspicuity (or intended to improve the accuracy of judgements of motorcyclists' speed or time to contact by other road users)
2. The study must involve either collection of data, or the analysis of existing datasets (i.e. based on evidence rather than speculation or opinion)
3. The study must involve treatment(s) or experimental manipulation(s) of some kind (i.e. the impact of an intervention or experimental condition on the outcome measure is considered)

Against each of these three criteria the researchers were able to score a 'yes', 'no' or 'maybe' (the latter being where there was insufficient information contained within the abstract to decide). All papers rated as either a 'yes' or a 'maybe' against all three criteria were taken forward to the next stage (i.e. a definitive 'no' against any of the criteria resulted in the paper being excluded).

In order to save time in completing the first pass review the abstracts were split between two researchers, which required there to be some form of inter-rater reliability testing to ensure parity. To this end 22 papers were selected at random for both researchers to code, of which 21 returned the same result of whether or not to go through, thus giving over 95% inter-rater reliability. A third researcher checked all the papers excluded at this stage to help ensure that none were excluded in error.

In total 115 papers were identified to be taken forward for the full-text filtering, although in practice only 95 of these were obtained. This was due to 20 papers being either only available in a language other than English, or being otherwise unobtainable.

4.2.2 Full-text review

Full-text copies were sought for each of the papers that made it through the first-pass filtering as 'yes' or 'maybe'. These were then scored according to the same principles as for the abstract review (i.e. against the inclusion criteria), which resulted in the final set of papers to be scored on the basis of the following quality criteria:

1. The use of appropriate experimental design methods to ensure that any effects shown are attributable to the intervention, and are not simply artefacts of the design (for example practice effects, or other variables that are confounded with the intervention).
2. Reporting of levels of statistical significance to allow ruling out of results that are likely to be due to chance fluctuations in the data.

It had originally been the intention of the research team to grade studies on the extent to which effect sizes were reported for the different interventions so that some assessment of likely real-world impact on NZ crash statistics could be made. However in practice the variability of methods used in the studies made this unworkable. Instead, we consider this issue when addressing the next steps in Section 6, including an assessment of the likely impact on NZ crash statistics through different intervention types working on different underlying accident mechanisms.

In total, 27 papers were deemed to meet the criteria for inclusion in the study and were taken forward for a full review on the basis of the quality criteria (although see Section 4.3 for discussion of papers on daytime running light legislation).

4.3 Final review

The key aim of the inclusion and quality criteria was that any conclusions drawn were based on the most relevant and best available evidence.

Each paper that met the inclusion and quality criteria was reviewed to obtain the specific information considered relevant to the goals of the study. In order to further reduce the number of papers subject to full scrutiny, papers that dealt exclusively with the effectiveness of daytime running light *laws* were excluded from the full review (not least because such a law already exists in NZ). This literature is nonetheless summarised briefly in Section 5.

5 Findings

Table 5-1 lists the papers included in the full review, by broad intervention type. Each of these broad intervention types is discussed separately in this section. First we deal with the separate issue of laws to require the use of daytime headlamps on motorcycles; this law already exists in NZ, but it was nonetheless felt relevant to the context of the review that this be covered. We then discuss experimental studies that have looked at the actual effectiveness of different lighting interventions, clothing interventions, and other types of interventions. In all sections, we attempt to consider the part of the LBFTS continuum discussed in Section 3.2 that is addressed by the intervention under review; however as will be seen, because the definitions discussed in Section 3 are not static (i.e. they have developed over the same period as the research) and because research papers have not always sought to define exactly what is being studied, this is not always obvious.

5.1 Daytime headlamp laws

5.1.1 Daytime headlamp laws for motorcycles

Daytime headlamp laws require that vehicles have the main (dipped) headlamp, or dedicated running lights, on continuously to act as a conspicuity aid during daylight hours. Typically these laws relate solely to motorcycles, as is currently the case in New Zealand. Research into legislated headlamp use typically involves conducting comparisons of road casualty statistics before and after an introduction of a change in the law. Given that daytime headlamp use for motorcycles is already a legislated requirement in New Zealand, research into this topic is summarised here only briefly, with a few examples selected to highlight some of the key messages.

The nature of conducting comparison studies of road casualty data means there is an inherent difficulty in mitigating completely the potential confounding factors, as there will often be changes over time or between locations that may partially explain any changes seen in data before and after the change of interest. What must usually be attempted is to balance the data to take into account such confounding factors, which in itself presents challenges as there is introduced a certain degree of subjectivity as to what an appropriate balancing approach should be. An example of this problem is presented in two research papers from the 1980s, both of which were published in the American Journal of Public Health and used broadly the same data, yet produced conflicting results. Muller (1982) examined motorcycle fatalities in the 50 US States and the District of Columbia between 1975 and 1980, seeking to determine if there were overall differences in the rates of motorcycle fatalities between states where daytime headlight use was mandated and those in which it was not. The analysis suggested that there was no significant difference between the two conditions. Zador (1985) conducted ostensibly the same study (although using data from 1975 to 1983) and found that there was a significantly lower fatal accident rate in states where daytime headlamp use was mandated. The difference in these findings appears to arise due to the assumptions made in each study as to which data should be included or excluded, and how to balance for confounding factors. For example, Muller excluded single-vehicle crashes from the analysis, but Zador included them, arguing that a fifth of all single-vehicle crashes result from attempts by motorcyclists to avoid other vehicles and so related to conspicuity. In addition Zador used only data from states for which the status on daytime lighting laws did not change throughout the 9-year period being analysed, whereas Muller excluded data only for the year in which the change took place. This example illustrates the problems inherent in road casualty data analysis (and thus the evaluation of the success of legislative changes in general). It should however be noted that such analyses do have the advantage that they seek to measure directly the impact of an intervention in the real world and thus do not require that inferences be made from findings in simplified laboratory settings and applied to the usually more complex reality of the situation in the real world.

Typically in public health analyses of this type, where extremely high-quality study designs (such as randomised control trials) are not available, a 'weight of evidence' approach is taken whereby consistent findings combined with plausible underlying mechanisms of effect are taken as an indication of the efficacy of a given intervention; a good example of this in road safety is the recent Cochrane review on graduated licensing systems (Russell, Vandermeer & Hartling, 2011).

When viewed in these terms, the literature shows generally that mandatory daytime headlamp legislation for motorcycles has a positive effect on motorcycle accident rates, which it would be expected to do given the plausibility of the underlying mechanism of effect; essentially this is through increasing the visibility, search and attention conspicuity of motorcycles during the daytime, thus meaning that it has the potential to act upon the second and third failures identified in the LBFTS continuum in Figure 3.1.

Taking two of the more recent examples, Umar et al (1996) and Yuan (2000) both evaluated the effect of the introduction of mandatory daytime headlamp legislation (September 1992 in Malaysia and November 1995 in Singapore respectively). The data collected within each study showed that there was a significant reduction in the number of conspicuity-related collisions following the implementations of the laws, and this finding is consistent with the literature as a whole on such legislative interventions. Despite this, caution should be exercised when attempting to generalise findings from this literature to the NZ context, especially if trying to estimate what the quantitative impact of such legislation in NZ is likely to have been. One reason for this is that the effectiveness of such legislation may be partly dependent on the frequency with which motorcycles and similar vehicles are encountered, and this can vary substantially between countries. For example the World Health Organisation (2009) report that the percentages of registered vehicles in Malaysia, Singapore and NZ that are powered two- or three-wheelers are 47%, 17% and 3% respectively.

5.1.2 Daytime headlamp laws for vehicles other than motorcycles

In some countries, including members of the European Union, there has been a gradual introduction of continuously-on daytime lighting for all vehicles, which might become a legislated requirement in the future. It has been suggested that the widespread adoption of daytime lighting usage in the vehicle fleet (i.e. amongst cars and trucks etc. as well as motorcycles) may actually serve to increase the risk to motorcycles. The reasoning behind this is that if all vehicles have their lights on, the conspicuity advantage of motorcycle headlights is lessened as they are no longer a bright conspicuous light against an otherwise unlit background but are rather one of many lights in busy traffic scenes.

In a recent study Jenness et al. (2011) investigated the evidence for this potential effect by comparing two-vehicle fatal collisions in jurisdictions (Canada, and some US states) with and without widespread adoption of daytime lighting in the vehicle fleet at large. The approach taken was to identify collision types that might be expected to be influenced by DRL (broadly, those where the frontal conspicuity of a vehicle could plausibly help avoid the collision, such as violations of vehicle path); crash data were then examined to understand if DRL laws are associated with differential reductions in these types of crash (when compared with those crash types that might be expected not to be helped by DRL, such as rear-end shunts). Jenness et al. found that widespread adoption of DRL did indeed appear to increase the relative risk for DRL-relevant fatal motorcycle crashes, particularly so on urban roads (where the underlying mechanism described above would be expected to be strongest, due to the larger numbers of vehicles one would expect to see in urban environments). The authors caution against over-generalisation of their findings due to several limitations. One key limitation reported is that the jurisdictions differed not only in terms of DRL penetration in their vehicle fleets, but also in terms of helmet laws (Canada has a universal helmet law, while some US states do not). Another limitation is that only fatal accidents were considered, and it is possible that these differ from nonfatal crashes in a number of other ways that may preclude generalisation. Notwithstanding these limitations, Jenness et al. recommended that in light of their findings regarding the possible detrimental effects on motorcyclist safety on urban roads, if DRL for the wider vehicle fleet continues to rise then other measures should be taken to increase motorcyclists conspicuity at the same time, and in such a way that motorcyclists are given a 'visual signature' that is not reliant simply on lights that may be confusable with the lights used on the majority of other traffic. Recent work has looked at this issue experimentally. Cavallo & Pinto (in press) have shown that when cars have their lights on, motorcycles with their lights on are indeed more difficult to detect, although novel lighting configurations such as yellow lights and lights on the rider's helmet as well as the motorcycle appear to help redress this balance.

When making decisions about the implementation of DRLs in the wider vehicle fleet, a number of issues need to be considered. The impact on motorcyclists is one, but in addition an argument can be made that the public health benefit overall may still be positive (as has been found in most studies – see Cavallo & Pinto, in press); one possible reason for this is that if cars have their lights on in the daytime this can help all other road users detect oncoming cars. However again when trying to quantify any likely effects in NZ, specific contextual factors will need to be considered. For example see Elvik (1996, cited in Cavallo & Pinto, in press) for a discussion of the greater impact of DRLs in contexts with lower surrounding luminosity. The frequency of motorcycles as a proportion of road traffic is also likely to impact on the effect of vehicle DRLs. Daytime running lights for vehicles other than motorcycles are not strictly a measure designed to improve motorcyclist conspicuity, and are therefore outside the scope of this review. However the issue is mentioned here because it is relevant to the second and third potential failures identified in the LBFTS continuum outlined in Figure 3.1, and to inform MSAC's thinking in terms of possible future legislative changes in NZ.

5.2 Experimental lighting research

The papers reviewed in this subsection differ from those in Subsection 5.1 in that they used experimental methods to evaluate different treatments, as opposed to the analysis of road casualty data in response to changes in daytime running light laws. We review these studies to assess the kinds of lighting treatments that have been shown to have an impact on motorcycle conspicuity. One thing to be borne in mind is that much of the work reported does not replicate the cognitive load typically experienced while driving. Therefore it is difficult to be sure if the findings from such studies will transfer to real world driving in absolute terms. Relative differences between the various treatments studied are more likely to hold, but any quantification of effects in real world driving in the NZ context are likely to required validation studies that are either held in that context, or mimic it in some other way.

5.2.1 Front lighting

Thirteen papers were identified that related to the experimental evaluation of the use of lighting to make the bike/rider more conspicuous from the front, i.e. when approaching an observer. These papers between them covered two fairly distinct aspects of motorcyclist conspicuity. These are the basic detection of the motorcycle/rider as an object in the field of view (visibility, search conspicuity, attention conspicuity), and what this means in terms of the observer's appraisal of that object as a motorcyclist and their consequent behavioural response.

5.2.1.1 Detection

Williams and Hoffmann (1976) was the first example in the literature included of a study purely intended to assess the relative conspicuity of different lighting conditions simply in terms of being detected by an observer. Participants were tasked with detecting whether or not a conspicuity aid was present in a series of photographs, representing either cluttered or uncluttered environments, with the images flashed up for 1/25th or 1/125th of a second respectively. Among other treatments (discussed later) the study compared a motorcycle with a low-beam headlamp, a motorcycle with high-beam headlamp, and a control motorcycle with no headlamp. Williams and Hoffmann followed-up this work with a publication in 1979, along similar principles, but which also looked at reaction times. Both studies found that the high-beam headlamp was identified significantly more frequently than the low-beam. The value of this study is limited given that participants were tasked with identifying a conspicuity aid rather than the motorcycle itself. In addition the plausibility of always-on high-beam headlights is debatable given the issues of glare associated with their use for other road users; however the study was able to show how lighting could be used for the benefit of improving search conspicuity and thus helped pave the way for future research.

Donne and Fulton (1985) is the first study included in the review that sought to examine the influence of lighting on detectability through the use of experimental field trialling. Participants were positioned in a parked car facing oncoming traffic and given periodic glimpses of the road scene using tachistoscopic occlusion apparatus. With each glimpse they were asked to identify whether there were any vehicles present and, if so, what the lead vehicle was (effectively this is measuring search conspicuity for vehicles, although to the extent that participants were not directly asked to look for motorcycles it could be argued that attention conspicuity was also being assessed for motorcycles). The researchers compared frequency of correct identifications for four headlamp configurations. These were a control condition with no headlamp lit, two 15 Watt handlebar-mounted DRLs, a 40 Watt large headlamp with dipped beam, and a 15 Watt DRL mounted below a headlamp. Also assessed was a fifth configuration where the rider was wearing a fluorescent orange jacket but with no lights. The study found that the 'single headlamp' and the 'two 15 Watt DRL' conditions both resulted in significantly higher detection rates compared with the control condition. Although not statistically significant there was a suggestion that the single headlamp may have been more effective than the dedicated DRLs. The study did not test the effect of combining the dedicated DRLs with the main headlamp. A later study by Donne and Fulton (1988) showed similar results with illuminated leg-shields.

Dahlstedt (1990) investigated conspicuity in a study in which participants were given a one-second viewing of a motorcycle, ridden out from behind a stationary vehicle at an angle of either 5° or 30° to the viewer, and were asked to rate its visibility. In addition to variations in motorcycle size and colour, and rider clothing, the study looked at different combinations and colours of both steady-state and modulated (flashing) headlamps. Under the steady-state category the study found that combining the headlamp with always-on sidelights was rated as being more visible than either independently, and having both showing a yellow aspect was rated as more visible than mixed white and yellow aspects. Unsurprisingly, a high-intensity front light was rated as more visible than a low intensity light. The study found no differences in the rated visibility of the motorcycle as a function of the modulation frequency of the front lamp.

Hole et al. (1996) introduced the concept of different background environments as a potentially relevant factor in determining conspicuity. Three experiments were conducted in which participants were shown images with or without a motorcycle present. The three experiments used a semi-rural road, an urban one-way street and a university campus road, with reaction times to detect motorcycles measured. Headlight use proved to be effective in reducing response times in the semi-rural environment, but not in the urban environment. In the university campus setting the headlamp was effective when viewed at distance and against a cluttered background but offered only negligible improvements against an uncluttered background. This study is important in that it illustrates the need to consider any conspicuity aid (in this case a measure of search conspicuity) as situational; since the key underlying factor that seems to determine conspicuity is contrast with a background, the usefulness of a conspicuity aid will vary with background.

Langham (1998) represents the first instance of an attempt to conduct experimental laboratory trialling using moving images, and also introduced the concept of participants' cognitive style (field dependent or independent[4]) as an additional factor; this was measured through the use of the Embedded Figures Task (see Wapner, 1991, cited in Langham, 1998). As with earlier studies involving static images, participants were shown clips that did or did not contain a motorcycle, and they were presented in either a cluttered or uncluttered environment, and at 50m or 100m viewing distances. Participant reaction times were taken as the dependent variable for the analysis. Headlight use was found to reduce reaction times for detection compared with a bike with the headlight off and it was also found that headlights reduced the negative effects of viewing against a cluttered background that were seen in the headlight-off condition. One key finding

[4] Field dependence is a concept for differentiating people according to their different cognitive styles. Those who are said to exhibit field-dependence tend to rely on the information present in the world around them in their appraisal of a situation, whereas those said to exhibit field-independence tend to rely more on their own experiences and personal constructs. In terms of detecting stimuli in the environment, field-independent individuals are more readily able to distinguish complex shapes from their backgrounds than are field-dependent individuals.

however in this study was that the field-dependent participants produced longer reaction times and were also more heavily influenced by the headlights being on or off, especially at longer distances and against cluttered backgrounds. Figure 5.1 shows this pattern of data. This finding is important in that it demonstrates two things. First, that there are individual differences in the ability to detect stimuli in complex traffic scenes, even when they are being searched for directly (i.e. when the middle areas of the LBFTS continuum in Figure 3.1 are being considered); 'one-size fits all' solutions are thus unlikely, especially in very challenging viewing environments (such as cluttered backgrounds and long viewing distances). Second, the data illustrate the considerable benefits of lighting at longer viewing distances on basic detection (see Section 5.2.1.2 for a discussion of how lighting can also be used to help with appraisal of oncoming vehicle speed).

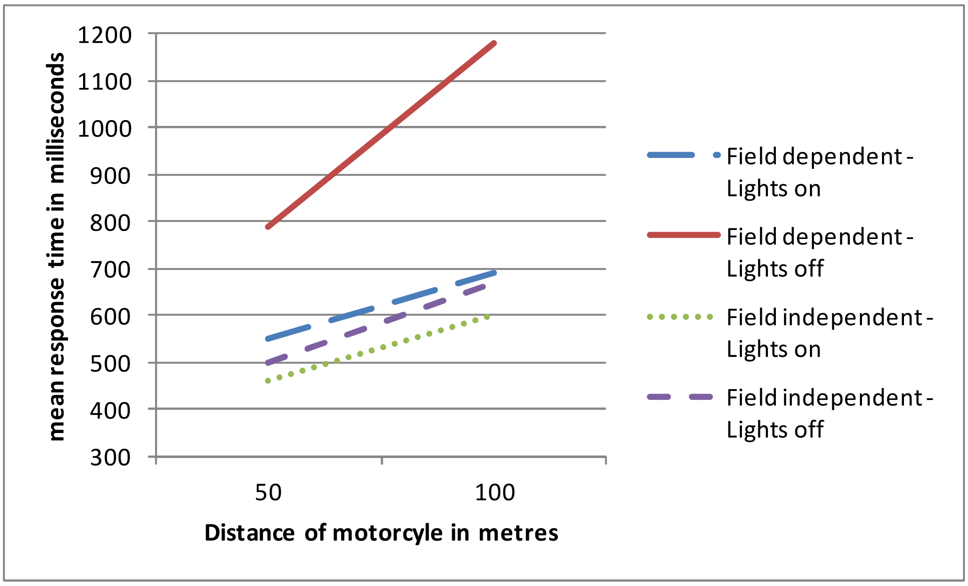


Figure 5-1: A figure illustrating the general pattern of times for field dependent/independent participants to detect motorcycles against cluttered backgrounds from Langham (1998)

Pinto and Cavallo (2011) published a study in which positioning of supplementary lighting in more novel orientations was examined. Participants were shown photographs of street scenes that either did or did not contain a vulnerable road user (pedestrian, cyclist or motorcyclist) in a 50:50 split. Images were shown for 250ms and participants were asked to press a button if a vulnerable user was present. The addition of pedestrians and cyclists were intended to prevent participants specifically looking for motorcyclists and the relatively low frequency with which images containing motorcyclists were presented further helped to reduce participant expectation. Motorcycle/rider lighting configurations tested were a standard headlamp as a control, a standard headlamp plus two additional DRLs mounted on the rear-view mirrors, a standard headlamp plus an additional lamp on the rider's helmet, and a standard headlamp but shown with a yellow aspect as opposed to the usual white. The study looked at detection over various distances and, taken as a whole, none of the configurations tested showed significant improvements over the control. However, at further distances the 'yellow lamp' and the 'standard headlamp plus helmet lamp' configurations showed significantly improved detection rates compared with the control. This suggests that such treatments can make a motorcycle stand out more when the road scene is being searched directly for multiple vulnerable road users.

5.2.1.2 Appraisal / behavioural response

The papers reviewed in this subsection measured drivers' behavioural responses to motorcyclists rather than detection. This branch of research can therefore be considered as potentially moving more towards the far right of the LBFTS continuum described in Section 3.2, in that differences might be expected in behavioural response even if motorcycles are detected.

Kirkby and Stroud (1978) assessed gap headways accepted by drivers entering a large roundabout in front of a motorcycle that was repeatedly ridden around the roundabout by a test rider. The motorcycle had either no headlamp lit or a dipped headlamp, and no difference was found in the median gap times accepted. However, the authors themselves noted in hindsight that median headway times may not have been the best choice of measure[5].

Mortimer and Schult (1980) also assessed gap acceptance by other road users turning in front of test vehicles when driven on public roads. The test vehicles used were a car with dipped headlamps, a motorbike with dipped headlamp, and a motorbike with dipped headlamp plus two wide-mounted DRLs in a horizontal configuration. Crucially, the study in this case used mean headways for the analysis and found that the average accepted headway gap was largest for the car, followed by the bike with DRLs, followed by the bike with single headlamp.

More recent research has seen a shift in focus within the research community to the importance of the arrangement of supplementary DRLs as a means of conveying information on the approaching speed of a motorcyclist, through provision of a larger surface area of lighting to permit this judgement.

Tsutsumi and Maruyama (2007) provide an innovative example of this kind of research. Participants were positioned in a vehicle waiting to make a turn across the path of an oncoming motorcycle, and were asked to press the brake pedal the point at which they would no longer make the turn (termed the critical time gap, or CTG). The approaching motorcycle had either conventional lighting (a single headlamp) or a configuration of lighting with two extra lights on the high wing mirrors of the bike, and two extra lights on the bottom of the front forks. A car was used as the comparator. When expressed as a percentage of the car CTG, in night time the modified lighting system was 98.9%, while the normal headlight only configuration was 81.8%, a statistically significant

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[5] The mean is the most commonly-used method of calculating an average. It takes into account every data-point as part of the calculation, but in doing so it can become 'distorted' by outlying values. The median is an alternative method of calculating an average value that is intended specifically to negate the influence of outliers, essentially by excluding their excessive influence on the central estimate. In the case of the Kirkby & Stroud (1978) study the authors were seeking to detect a change in gap acceptance as a result of a (probably) fairly small subset of participants who may have failed to identify or appraise correctly the approaching test rider and thus might have been influenced by the presence or absence of a lit headlamp. This subset would in essence become a group of outliers in the data (or at the very least clustered at one end of the spectrum), except that rather than 'distorting' the average gap acceptance score for each trial, they would have revealed that a subset of the driving public are particularly susceptible to the effect in question. In this case the mean would have been a more appropriate measure to use, as a subset of 'outlying' participants would have had the opportunity to influence the result, as was the premise behind the study. Instead, using the median effectively excluded the very participants whom the study was supposed to be investigating.

difference between the two conditions. This result was replicated in daytime testing, with the values for the modified lighting and normal headlight at 99% and 93% respectively (again a significant difference).The study also showed in daytime that the normal headlight performed better than the motorcycle with the headlamp off (this condition having a CTG of 86.5% of the value of the car).

Jenness et al. (2011) continued the work of Mortimer and Schult in examining driver gap acceptance in front of approaching motorcycles with different lighting configurations. Participants were positioned in a stationary car, parked on the verge, and were asked to imagine turning across oncoming traffic into an imaginary road marked by two cones; releasing a button at any time when they would no longer be prepared to make the turn. The purpose of the trial was disguised by asking participants to wear fake eye-tracking equipment and telling them that their eye movements when assessing gaps in traffic were being examined. In addition participants were distracted with a secondary task of pressing a second button when a white lamp was illuminated (the light turned on at random intervals between 12 and 24 seconds in length) above one of the cones, thus requiring them to glance away from the oncoming traffic. This distraction task was used to ensure that participants could not simply focus all of their attention on the oncoming traffic (in other words it was used to make the task more representative of the cognitive effort in real driving, when complete focused attention is rarely possible). The lower quartile boundary of all the gap acceptance thresholds measured in the study was used to define the threshold below which it might be considered inappropriate to accept a gap (a 'short safety margin' of 3.44 seconds) and the relative proportions of gaps below this threshold that were accepted were used to compare the different trial conditions. The conditions tested were modulated high beam headlamp, low beam plus low-mounted auxiliary lamps, low-beam plus high-mounted auxiliary lamps, low beam plus high and low-mounted auxiliary lamps, low-beam plus low-mounted LED lamps, and a low-beam-only control. The results showed that the proportion of gaps accepted below 3.44 seconds was lower for all test conditions compared with the low-beam control, but only the low-mounted auxiliary lamps and the modulated high-beam were statistically significant (19% and 16% respectively compared with 35% for the control).

Gould et al. (2012) looked specifically at the ability of participants to judge distance and approaching speed of a motorcycle under different lighting configurations in an experimental laboratory setting. The study also investigated this effect under both daylight and night-time conditions. Participants were shown computer-generated clips of simulated vehicles approaching the camera. Pairs of clips (each 0.5 seconds in duration) were shown, with an interval of 0.25 seconds, and participants asked to state in which clip the vehicle was travelling faster towards them. Unbeknownst to participants, in all clips the vehicles were modelled with a time-to-passage[6] of 4 seconds and one of the clips in each pair was of a car travelling at 30 mph (this was the reference vehicle). The comparison vehicles assessed were a reference car with 160cm headlamp spacing (the same as the reference vehicle), a motorbike with single headlamp, a motorbike with single main headlamp and two smaller lamps placed 30cm below and to the right and left of the main lamp, the same but with smaller lamps above headlamp, a motorbike with lamps in vertical arrangement, one 30cm above and one 30cm below main lamp, and the same but in a horizontal arrangement. One study compared the first three of

[6] Time to passage means the time for the oncoming vehicle to reach the observers position. 'Time to arrival' and 'Time to Contact' are also commonly used in the literature, and mean the same thing.

these comparison vehicles in both daytime and night-time conditions; a separate night-time-only study compared the final four. In the first study the daytime results showed better speed judgements on average for the car than either of the motorcycle conditions, whilst the night-time results showed the single headlamp condition was significantly worse than both the car and the tri-headlamp configuration. The separate night-time-only tri-headlamp trial showed that auxiliary lamps both placed either above or below the main lamp performed better than when arranged horizontally. Thus the study shows that headlamp configuration can aid speed estimation (and therefore provide more accurate decision making as to the time available for a manoeuvre) in night-time conditions.

5.2.2 Tail-lights

Some research has been carried out into the conspicuity of motorcycles from the perspective of a following driver. Although not strictly speaking a 'LBFTS' accident scenario, similar perceptual mechanisms can be argued as being at play. In particular, the small size of motorcycles is still an issue for detection and for an appraisal of time-to-contact if the motorcycle has slowed down or stopped, and the lack of 'high level' brake lights may accentuate this problem. Tang (2003) and Tang et al. (2006) both compared a standard (red) brake-lamp with a modified setup in which the (amber) turn-signal lamps would also flash when the brakes were applied. The 2003 study assessed reaction times to detecting the lamps in an on-road study and found these to be quicker for the modified lamp than for the normal lamp. The 2006 study was an experimental trial that repeated the reaction time test of the earlier study and included an additional assessment to test whether the flashing turn signals had any negative side-effects in reducing reaction times in response to a normal turn-signal activation. The results showed response times to normal turn signals increased by 122 ms but response times to brake activations decreased by 200 ms with the modified system in place. Both of these changes were statistically significant. The authors argued that because braking as part of turn manoeuvre is typically much less severe than for an emergency brake application, the potential safety benefit that might be expected from the reduction in reaction times to the braking response far outweighs the potential disbenefit that may arise from the increase in response times to the normal turn signal.

5.3 Conspicuous clothing

The review identified 12 studies related to efforts at increasing rider conspicuity through the design of clothing, with much of this work being done in the late 1970s. Several of these studies have previously been discussed in the context of lighting measures as many, particularly the earlier studies, looked at a wide range of measures in the same paper. Note that helmets are considered as clothing for the purposes of this review, except where lighting has been placed on them (for example in Pinto and Cavallo, 2011).

Hazlett et al. (1969) looked at the use of retro-reflective patterns on motorcycle helmets as a means of improving conspicuity at night. The study assessed square, triangular, rectangular and circular patterns in addition to a helmet sprayed with retro-reflective material and a basic white helmet as a control. The study found all the test measures could be detected (when searched for) at a greater distance than the control but with no other significant differences between them.

Williams and Hoffmann (1976, 1979) conducted research, already covered in Section 5.2.1, in which participants were shown brief glimpses of photographs showing motorcycles in clean or cluttered environments, and were asked to state if a conspicuity aid (from a list that included, among others, a rider wearing a red jacket) was present. No significant effect of the jacket was observed, although as previously mentioned, the study was perhaps limited in its value at any rate due to the difficulty in ascribing any usefulness to a participant's ability to identify a specific conspicuity aid when looking for it as opposed to the detection of the motorcycle itself.

Lalani and Holden (1978) conducted a study of road casualty data before and after the 'Ride Bright' campaign conducted in 1976 in London, in which riders were encouraged to wear bright clothing and ride with their headlights on during the day. Survey evidence showed that the campaign was effective in terms of rider behaviour (increases in bright clothing wearing and light use was observed to go up) and the road casualty data showed a reduction in the number of accidents (when balanced to account for general underlying trends in the figures) following the campaign. However, the study is of limited value for assessing the effect specifically of bright clothing as there is no way to differentiate between the effects of increased bright clothing, increased daylight headlight use, or simply the potential behavioural effects of running an awareness campaign on drivers' expectancies. Whilst not a legislative implementation, this study suffers from some of the difficulties in balancing for confounding factors as were highlighted in Section 5.1.

Also discussed earlier (see Section 5.2.1.2) was the study by Kirkby and Stroud that investigated gap acceptance by drivers entering a roundabout, comparing accepted gap size for a control rider dressed in plain clothing, a rider in the same clothing but with a dipped headlamp on, and a rider wearing a fluorescent jacket. Although no differences were observed, as already mentioned, the use of median gap size as the outcome measure probably contributed to this.

Olson et al. (1979) also looked at gap acceptance. The study incorporated both day and night-time testing and looked at a greater range of conspicuity aids. The study examined some lighting and fairing designs, but with regards to clothing examined a fluorescent orange vest, a fluorescent orange helmet cover, a fluorescent orange vest and helmet cover, a fluorescent green vest and helmet cover, a fluorescent orange vest and helmet cover plus a modulating lamp, and a retro-reflective vest and helmet cover for night-time trialling. The study also looked at the influence of a car following at various distances and the effect of lane positioning of the bike. The study found all the fluorescent clothing to be effective in increasing the gaps accepted by drivers compared with a control rider in plain clothing. At night the retro-reflective clothing was found to be more effective than running turn-signal lights, but only when the car and rider were facing head-on.

Fulton et al. (1980) incorporated gap acceptance tests into a study that also used experimental lab and field trialling of rider detection as a function of various clothing designs. The gap acceptance trial found no significant differences in gaps accepted between the various clothing conditions, but the lab and field trials both found a fluorescent jacket or fluorescent waistcoat to be effective in improving rider conspicuity compared with a control rider in plain clothing. The lab trial was based on time taken to identify a rider in various photographs and the field trial was based on the proportion of pedestrians who saw a rider at an intersection in various attires, and so the differences in findings may reflect differences in the measures used (the gap acceptance study may have been measuring the appraisal end of the LBFTS continuum in Figure 3.1, while the lab and field trials were probably measuring effects on search and attention conspicuity), and this illustrates that measures that improve visibility may not always contribute to changes in behavioural responses seen at junctions.

Donne and Fulton (1985) represents perhaps the earliest study that attempted to measure objective rider conspicuity in the sense one might consider reasonably analogous to real-world conditions (providing drivers with glimpses of a real road scene and asking them to identify if a vehicle was present and, if so, what it was). A rider wearing a fluorescent jacket was correctly identified more frequently than was a rider in plain clothing.

Dahlstedt (1990) also used a methodology in which participants had a brief glimpse of a scene, but in this case it was in an off-road setting and participants knew they would be glimpsing a motorbike with each viewing. The purpose was therefore to build up a picture of subjective ratings of visibility. The study found that participants rated a fluorescent helmet and jacket combination to be more conspicuous than white, both of which were rated as more conspicuous than grey or black.

The results relating to headlamp usage in Hole et al. (1996) have already been reported in Section 5.2.1, but these authors also examined clothing types in their study in which participants searched directly for motorcyclists in pictures of road scenes. Up to this point the research literature all pointed towards bright clothing as being more conspicuous, but the context (i.e. backgrounds) in which this was the case had never been properly examined. Interestingly the data from this study showed that plain dark clothing was more conspicuous against a light semi-rural background, but also against an urban background[7]. In relation to clothing (as in relation to lighting) this study was important in that it highlighted the need to consider conspicuity interventions in terms of the context in which they are going to be used.

A recent study by Rogé et al. (2011) directly assessed the issue of background contrast in a driving simulator. Participants drove a simulated route in which they would encounter various motorcycles in different situations. Their task was to flash their headlights whenever they detected a motorcycle (again a measure of search conspicuity); the distance from the motorcyclist was recorded as an indication of the motorcycle's conspicuity. The results indicated that a higher colour contrast between rider and background resulted in greater detection distances.

Gershon et al. (2012) adopted a similar experimental approach to that used by Hole et al. (1996), with participants being asked to study photographs of road scenes. In experiment 1, participants viewed photographs for 600ms and were then asked to report the type of motor vehicle present; the rate at which motorcycles were detected was measured, and the measure can be thought of as reflecting attention conspicuity (see Section 3.1). In experiment 2, the same photographs were used, and participants were asked to report whether or not there had been a motorcycle in the picture; their time to reach a decision was used as the measure of interest, and can be thought of as a measure of search conspicuity (see Section 3.1). In both experiments the independent variables investigated were distance from the observer (and hence stimulus size – very

[7] It should be remembered of course that the photos used were taken in the daytime. It is unlikely that dark clothing would have offered any benefit over lighter clothing at night.

small, small, medium, large), driving environment (rural road, urban straight road and urban traffic circle), and jacket colour (black, white, reflective). Broadly the results showed that for both attention and search conspicuity, the context in which the photographs were taken influenced which clothing was most effective. At the furthest viewing distance on the urban straight road the reflective jacket led to a higher detection rate in experiment 1 and faster detection times in experiment 2, when compared with the other clothing types. Again at the furthest viewing distance on the urban traffic circle the white jacket was best (although not significantly so for detection times under search conditions), and on the rural road the black jacket was best. At the next furthest viewing distance the pattern of results was broadly similar. At closer distances from the observer, the differences between the clothing types disappeared, presumably because at closer distances the rider was sufficiently conspicuous that detection became trivially easy. The results are interesting in that they show the previously held assertion that a bright reflective jacket will improve rider conspicuity may not always be true. When the findings from Hole et al. (1996) and Rogé et al. (2011) are also considered, the message seems to be that the most conspicuous outfit will be dictated by the lighting conditions and local environment at the time, which may be extremely variable within the confines of even a fairly short ride.

5.4 Other technology

The remaining papers uncovered fall into the 'other technology' category and generally relate to measures intended to make the structure of the bike itself more conspicuous. Much of this work can be drawn from the pool of studies reported in the previous sections (especially much of the work from the 70s and late 80s in which multiple classes of conspicuity aids were often assessed in the same study). Examples of this include the work by Williams and Hoffman (1976) and (1979), Olson et al. (1979) and Dahlstedt (1990). Williams and Hoffman found limited benefits of the addition of white fairing to a bike and any benefit was diminished in traffic. Olson et al. found the addition of fluorescent colouring to the bike to be less effective than when applied to the rider. Dahlstedt found that the addition of a fairing could be effective in improving conspicuity but only on a larger bike and if it was painted in fluorescent colouring. It is not clear why efforts to make the bike itself more conspicuous seem to be less effective than when applied to the rider. One suggested reason for this is that additional fairing coverage simply acts to obscure the rider (see Figure 2-3) meaning that there is no increase in the overall 'size' of the conspicuous object in the visual field. Another possible reason is that accentuating the bike rather than the rider detracts from the brain's natural ability to pick out the human form. The studies examined in this review also tended to look at fairing colour and clothing colour separately and it is not clear what effect various combinations of the two may have. In short, work into the conspicuity effects afforded by fairings has not led to any firm conclusions, and more research is needed.

There were a few studies that examined some more novel approaches. Burg and Beers (1978) investigated the effect of adding retro-reflective material to the sidewalls of tyres as a night-time conspicuity aid. Participants were positioned 500ft from a mock intersection and given a 3-second viewing of the scene ahead, which included various combinations of objects in addition to the test bike. Participants were then asked to state what they had seen (thus this was a measure of attention conspicuity). Detection rates for the bike with reflective tyre side-walls were significantly improved over a bike without (both with the bike headlights on or off). The effectiveness of such a measure in the real-world is perhaps limited as it requires a side-on view of the bike from distance, presupposing that the car and rider are approaching an open junction that provides unobstructed views. In addition, it requires the bike to be within the arc of the driver's headlights, which in reality would suggest that the motorcycle is in fact closer to the junction than the approaching driver and so a conflict situation is unlikely to arise in any case. Real world situations where the reflecting sidewalls pose an advantage may therefore be few.

More recently there has been innovative work conducted by Ino and Fujimaki (2006) into the use of smart warning devices to alert drivers of nearby riders when they are about to undertake a manoeuvre that may potentially bring them into conflict (for example when making a left or right turn at a junction). The system works by detecting vehicles approaching the junction using roadside cameras, and sending this information to the on-board computer of any vehicle equipped with the system. The authors claim improved driver behaviour when making such manoeuvres when the system is in place. However the technology is apparently still in its infancy and further research is required to put together a compelling case for its effectiveness, especially given that it is likely to be a costly solution with low adoption rates.

5.5 Summary

In earlier years the focus of research was on fairly basic assessments of daytime headlamp use and of brightly coloured clothing. When considering the weight of evidence overall, both seem to be capable of improving conspicuity, when this is measured in terms of detection (under search and attention conspicuity conditions), and when measured in terms of a behavioural response. The majority of studies covered in this review support this conclusion. However there are limitations and caveats.

In terms of lighting, although it appears that dedicated daytime lighting on motorcycles is effective in increasing conspicuity, this effect may be smaller when other vehicles have their lights on (although more research may be needed on this specific issue, especially in terms of understanding its impact on other accident types).

When lighting is arranged in such a way as to accentuate the form of the bike (and to provide greater information for judging approach speed), this may aid the observer in determining the distance and speed of the approaching bike (especially at night) although not much research has been done on this specific issue.

Across all treatments (clothing and lighting especially) there is evidence that colour can play a role in effectiveness; this may be especially true in settings where coloured motorcycle lights aid in the motorcycle standing out from surrounding vehicles which have white lights.

Although most studies reviewed show benefits of bright clothing, dark clothing may be better if the background is also brightly coloured. In line with the underlying mechanisms proposed, higher contrast with background surroundings to enable better visibility, search conspicuity, and attention conspicuity is what is needed. Given that environments may differ over even fairly small changes in time or location, there is not likely to be a one-size-fits-all solution, meaning that motorcyclists need to be aware of the limitations of whichever interventions they use. In terms of understanding what the literature review means for the NZ context, an understanding of the visual background typically present in NZ at crucial interaction points between motorcycles and cars will be required.

In addition, the acceptability of specific interventions to motorcyclists is an issue to be considered, especially when trying to understand the likely public health benefits.

Table 5-1: Studies of motorcycle conspicuity by intervention type

Intervention Type	Study	Study Type	Country	Participants	Measures	Design Issues	Results
Clothing							
	Hazlett, Courtney, Stockley & Allen (1969)	Experimental laboratory and field study	USA	N=20	**Laboratory**: recognition threshold and luminance level measured **Field**: Distance when stimuli was first detected and when geometric shape was determined	Spray paint was less reflective than tape used to create shapes, and was prone to bleeding in rain. Target recognition in field test was of the geometric shape and not of the helmet itself, therefore findings of limited practical significance.	**Laboratory**: Rectangular shape and bigger shapes in general, were easier to recognize. **Field**: No significant difference in detection distance between treatments but all were an improvement over the control. Recognition distance best with triangle.
	Williams& Hoffmann (1976) [1/2]	Experimental laboratory trial	Australia	N=10	Participants reported if conspicuity aid was present; Proportion of correct responses	Conditions may not be comparable due to random distribution of other vehicles around test vehicle. Ability to identify a conspicuity aid is not a good indicator of overall conspicuity.	No significant differences between fluorescent jacket condition and control.
	Lalani & Holden (1978) [1/2]	Observations and road casualty data analysis	UK	Riders in greater London	**Observations:** percent of riders wearing bright clothing or riding with lights on **Casualty analysis**: number of casualties before and after intervention	Intervention was a campaign promoting use of bright clothing and headlamps; data does not differentiate results. Accidents at night used as control on the assumption that these should be unaffected by the intervention.	Daylight accidents increased by 6.8%, whilst night-time accidents increased by 14.9%; it is therefore assumed that intervention has saved 8.1% daylight casualties. (570 casualties)
	Kirkby & Stroud (1978) [1/2]	Experimental field trial	UK	Drivers waiting to enter roundabout as rider passed.	Median gap headway time accepted by drivers	The premise behind the work was that smaller gaps would be expected from the subset of drivers who failed to spot or correctly appraise the approaching rider. Median gap was therefore a poor measure to use as it likely reflected gaps accepted by drivers who saw the rider and not those who didn't.	No difference in median gap accepted.
	Olson Halstead-Nussloch & Sivak (1979)	Experimental field study	USA	Motorists of a five lane thoroughfare	Proportion of drivers rejecting various headway gaps		At night, retroreflective clothing was more effective than running turn signal lights, but only for head-on.
	Williams & Hoffmann (1979)	Experimental laboratory trial	Australia	N=10	Response times; confidence of motorcycle detection		Exp. 1: Faster response times for high beam, jacked and bike alone in cluttered background. Exp. 2: All aids better than bike alone. Effectiveness of flaring and jacket reduced when in traffic.

Intervention Type	Study	Study Type	Country	Participants	Measures	Design Issues	Results
	Fulton, Kirkby & Stroud (1980)	Experimental lab study	UK	N=116	Time to identify rider in picture	Questions over ecological validity as pictures were used, and participants were tasked to find the motorcycle.	Jacket and waistcoat had significantly shorter times than control.
	Donne & Fulton (1985) [1/2]	Experimental field trial	UK	197 drivers	Frequency with which motorbike was identified during brief glimpses of the test road scene	Use of different test sites resulted in different findings per site; these are not discussed in detail.	All conditions showed improvement over control, but not in all sites. 40 Watt headlamp significantly better than fluorescent jacket.
	Dahlstedt,(1990) [1/3]	Experimental off-road study	Sweden	N=53	Rating of the visibility of a bike against a reference score	Results presented for each as a separate sub-study, with statistics from some easier to interpret than others.	Fluorescent helmet and jacket more visible than white, both more visible than grey or black. Addition of fluorescent fairing improves visibility but only at 30 degree angle.
	Hole et al. (1996) [1/2]	Experimental laboratory study	UK	Exp. 1: N= 30 Exp. 2: N=31 Exp. 3: N=40	Reaction time and accuracy in detecting presence/absence of motorcycle	Authors note limitations to generalizability: many UK roads are dark asphalt but road in Experiment 3 was light concrete; Mention of the difference between conspicuity in static images as opposed to dynamic scenes.	Exp. 1 & 2: Dark clothing improved detection in both rural and urban settings.
	Rogé et al. (2011)	Experimental simulator trial	France	42 car drivers, 21 motorcyclists, and 21 non-motorcyclists	Distance from which a motorcyclist was detected by the driver, in various situations	Inherent problems in creating and assessing contrast and brightness differences in a simulator.	When motorcycle appeared in front, detection distance higher with high colour contrast than with low colour contrast.
	Gershon et al. (2012)	Experimental laboratory trial	Israel	N=66	Detection rate (and reaction times) when identifying motorcyclists in photographs		**Exp. 1**: On urban straight road the reflective jacket was significantly better than the other two; on urban traffic white was best; and on inter-urban road the black was best. All at distance. **Exp. 2**: Significantly faster response times for white and fluorescent in urban traffic circle environment. Black quicker than both others in rural environment, but only at extreme distance.
Lighting - technology	Williams & Hoffmann (1976) [2/2]	Experimental laboratory trial	Australia	N=10	Proportion of correct responses when reporting if conspicuity aid was present or not	Conditions may not be comparable due to random distribution of other vehicles around test vehicle. Ability to identify a conspicuity aid is not a good indicator of overall conspicuity.	High beam headlights found to be significantly more detectable in both cluttered and uncluttered environments.

Intervention Type	Study	Study Type	Country	Participants	Measures	Design Issues	Results
	Kirkby & Stroud (1978) [2/2]	Experimental field trial	UK	Drivers waiting to enter roundabout as rider passed.	Median gap headway time accepted by drivers	The premise was that smaller gaps would be expected from drivers who failed to spot or correctly appraise the approaching rider. Median gap was therefore a poor measure to use as it likely reflected gaps accepted by drivers who saw the rider and not those who didn't.	No statistically significant differences between conditions.
	Williams & Hoffmann (1979)	Experimental laboratory trial	Australia	N=10	Response times; confidence of motorcycle detection		**Exp. 1**: Faster response times for high beam jacket and bike alone in cluttered background. **Exp. 2**: All aids better than bike alone. High beam better than low beam.
	Mortimer & Schult (1980)	Experimental field trial	USA	Vehicles turning in front of test bike and test car	Gap headway acceptance		Car returned longest average headway, bike with DRLs next, then bike with dipped headlight shortest; all gaps significant.
	Donne,& Fulton (1985) [2/2]	Experimental field trial	UK	197 drivers	Frequency with which motorbike was identified by the participants when given periodic glimpses of a street scene	Use of different test sites resulted in different findings per site; these are not discussed in detail.	All conditions showed improvement over control, but not on all sites. 40 Watt headlamp significantly better than single DRL.
	Dahlstedt (1990) [2/3]	Experimental off-road study	Sweden	N=53	Rating of visibility of a bike against a reference score	Results presented for each as a separate sub-study, with statistics from some easier to interpret than others.	For steady light, head and side light combined more visible than either independently. High intensity light more visible than low intensity.
	Langham (1998)	Experimental laboratory trial	UK	N=34	Reaction times detecting a motorcycle in video clips	Not all conditions randomised. Participants were classified by cognitive style, but no details on the procedure are given.	At both distances, headlight use reduced reaction times. Reaction times were longer against a cluttered background when headlights were off, but no effect when headlights on. 'Field dependent' subjects tended to produce longer reaction times, especially when headlights were off.
	Tang (2003)	Experimental field study	Taiwan	N=12	Time taken to brake in response to vehicle ahead braking	Possible order effects in presentation of conditions.	Across various lighting conditions, reaction time to modified brake lamp was faster than for conventional lamp.
	Tang et al. (2006)	Experimental simulator study	Taiwan	N=12	Reaction times in response to a brake light	Experiment performed on a screen with an LCD projector.	Response times to brake signals decreased with modified signal; response times to turn signals increased, but to a lesser extent.

Intervention Type	Study	Study Type	Country	Participants	Measures	Design Issues	Results
	Tsutsumi & Maruyama (2007)	Experimental field study	Japan	N=20	Critical time gap accepted in front of oncoming vehicles		Larger CTG for modified lighting system at night and during day. Single headlight also higher CTG than no headlight during day.
	Pinto & Cavallo (2011)	Experimental laboratory study	France	N=60	Detection rate identifying vulnerable road users in photographs		Helmet light significantly better than standard DRL, only for the 'far' condition. Yellow light significantly better, for far and central condition.
	Jenness et al. (2011)	Experimental field study	USA	N=32	Gap acceptance	May lack real-world applicability as participants had to imagine scenarios and gap acceptance was simulated.	Modulated high beam and low-mounted auxiliary lamps conditions yielded significantly fewer short gaps accepted.
	Gould et al. (2012)	Experimental laboratory trial	UK	N=13	Correct response rate when assessing relative vehicle approach speed		**Daytime**: reference car gave better speed judgements than all motorcycle conditions. **Night-time**: Judgements of the tri-headlight motorcycle were more accurate compared to solo headlight.
	Donne & Fulton, (1988)	Experimental study	UK	Unspecified	Proportion of correct identification of lead vehicle.		Motorcycles with illuminated legshields or striplights were identified more often than those with headlight only.
	Hole et al. (1996) [1/2]	Experimental laboratory study	UK	Exp. 1: N= 30 Exp. 2: N=31 Exp. 3: N=40	Reaction time and accuracy in detecting presence/absence of motorcycle in photographs	Authors note limitations to generalizability: many UK roads are dark asphalt but road in Experiment 3 was light concrete; Mention of the difference between conspicuity in static images as opposed to dynamic scenes.	**Exp. 1 & 2**: Headlight use effective in improving detection in rural setting but no significant effect in urban environment. **Exp. 3**: Headlight offered significant improvement in cluttered background at distance.
Other technology							
	Burg & Beers (1978)	Experimental off-road trial	USA	N=22	Detection rate of a test bike when viewed in a cluttered environment		Detection rates were significantly higher with reflecting tyres compared to non-reflecting tyres.
	Dahlstedt (1990) [3/3]	Experimental off-road study	Sweden	N=53	Ratings of visibility of the bike against a reference score	Results presented for each as a separate sub-study, with statistics from some easier to interpret than others.	Big fairing more visible than small fairing. Fluorescent more visible than yellow or white, all three more visible than black. Addition of headlight improves visibility at 5 degrees.

Intervention Type	Study	Study Type	Country	Participants	Measures	Design Issues	Results
	Ino et al. (2008)	Experimental field study	Japan	Left turn test: N= 6 ; Right turn: N=8	Driver response to left/right-turn collision warning system evaluated; Left turn: accelerator release point measured. Right turn: Time between oncoming vehicle passing through intersection and test vehicle beginning to make the turn was measured.	Very little information provided, particularly on statistical analyses. Measures used to assess effectiveness are somewhat abstract and inferred.	**Left turn**: Accelerator released earlier on average when warning given. **Right turn**: On average participants waiting longer before making turn when warning given.
Lighting legislation							
	Muller (1982)	Road casualty data analysis	USA		Motorcycle fatalities in the 50 US States and the District of Columbia between 1975 and 1980.	Accident rate differential between states mandating and not mandating daytime headlamp usage.	No significant difference in accident rates.
	Zador (1985)	Road casualty data analysis	USA		Fatal motorcycle crashes in the US from 1975 to 1983. (In states with a consistent legislative stance on daytime headlamp use within the period).	Accident rate differential between states mandating and not mandating daytime headlamp usage.	Significantly lower fatal accident rate in states where daytime headlamp use is mandated.
	Umar et al (1996)	Road casualty data analysis	Malaysia		Conspicuity-related motorcycle crashes between 1991 and 1993	Accident rates before and after the September 1992 introduction of compulsory daytime headlight use.	Significant reduction in the number of conspicuity-related motorcycle crashes following implementation
	Yuan (2000)	Road casualty data analysis	Singapore		Accidents reported to the Singapore Police from 1992 to 1996	Accident rates before and after the Nov 1995 introduction of compulsory daytime headlight use.	Significant reduction in the number of daytime fatal and serious injury accidents following introduction of legislation.
	Jenness et al. (2011)	Road casualty data analysis	USA & Canada		Crash data for the US and Canada from 2001-2007	Fatal crash-rate differential between states mandating and not mandating daytime headlamp usage.	Widespread use of DRL in the fleet increases relative risk for certain types of multi-vehicle motorcycle crashes, particularly in urban areas.

6 Discussion, conclusions and recommendations

6.1 Summary of findings

The current review took a systematic approach to reviewing the evidence for the effectiveness of interventions that have been designed to increase motorcyclist visibility and conspicuity. Recent work on interventions that seek to aid other road users in assessing the speeds of oncoming motorcycles at junctions (particularly at night) was also considered.

Although the review never sought to carry out a formal meta-analysis, it was hoped that some assessment of the effect sizes seen in different studies could be used to understand which interventions might have the greatest effects on motorcyclist safety. However the wide range of outcome measures used (for example identification of visibility aids, detection of vehicles from brief presentations, memory for detecting motorcyclists, gap acceptance, and judgements of speed) and the wide chronological and geographical spread of studies (meaning likely changes in traffic densities and lighting technology) convinced us that this was not a sensible approach. In addition, the review has shown that background contexts are important in understanding the effectiveness of different interventions, and these will differ considerably between jurisdictions.

Nonetheless, of the studies that we identified as of suitably high quality to include in the final review, most demonstrated that interventions designed to enhance the contrast of motorcycles with respect to the background in which they are presented (lighting or clothing) are generally effective either in improving rated visibility, speed or accuracy of detection (under search and attention conspicuity conditions), or in terms of improving appraisal of speed and behavioural responses. Important caveats on the ubiquity of interventions all make theoretical sense in that they rely on limitations as to the actual contrast differences obtained in some settings (for example a light colour of clothing on a light coloured background).

6.2 The New Zealand context

The review so far has concentrated on reviewing the wider literature on motorcycle conspicuity. In public health research the finding of interventions that work 'across the board' to treat a given issue (whether a disease or a road safety issue) is desirable. However it is often the case (especially in road safety) that interventions do not work equally well in all environments, usually either because the underlying mechanisms of effect are not equally applicable in all environments, or because the actual implementation of an intervention differs across jurisdictions. An example of the latter can be seen in the medical literature; there is evidence that antiretroviral drugs can reduce mother-to-child transmission of HIV infection (e.g. Volmink et al., 2007), but without community-level distribution this effectiveness is reduced (see e.g. Amuron et al., 2009), presumably because those who need the drugs are unable to travel long distances to central distribution hubs to access treatment. An example of the former, theoretically and empirically, has been discussed already in this review. Findings such as those of Gershon et al. (2012) and Hole et al. (1996) have shown that those conspicuity interventions that are most effective vary with different background contexts; this is entirely compatible with the theoretical underpinnings of the way conspicuity works (see Section 3.1). In addition, the findings from Gould et al. (2012)

on the effectiveness of a tri-headlight formation on improving drivers' ability to detect motorcyclists' oncoming speed showed that this is maximally effective under conditions of very low lighting.

A thorough assessment of all possible road and intersection contexts in New Zealand is clearly not possible within a single review. However it is possible to consider road casualty statistics and make some assumptions regarding likely characteristics of different junction types to get an idea of whether the interventions discussed in the current review are all likely to be applicable to the New Zealand context, and what their relative contributions to public health might be.

Official motorcycle collision statistics from New Zealand for the year ending 2010 (New Zealand Ministry of Transport, 2011a, tables 33 and 34 excluding pedestrian accidents and miscellaneous) show that 37.7% (465) of all injury crashes involving motorcyclists occurred on urban (speed limit less than 70 km/h) junctions and intersections, while only 5.9% (72) occurred on 'open road' (speed limit greater than 70 km/h) junctions. For fatal crashes involving motorcyclists, 12.6% (6) occurred at urban junctions and intersections, while 23% (11) occurred at junctions and intersections on the 'open road'. Therefore, assuming that equal proportions of fatal and injury accidents occurring at urban and rural junctions might have been avoided by measures designed to increase motorcyclist conspicuity, the potential public health benefit in terms of reducing the absolute number of collisions would appear to be highest at urban intersections. However to make a judgement on this issue it is necessary to consider the estimated costs of injuries of different severities, and fatalities.

According to NZ statistics (NZ Ministry of Transport, 2011b), the average social costs per reported crash (adjusted for non-reporting) is $4,322,000 for fatal crashes, $749,000 for serious injury crashes, and $80,000 for minor injury crashes. New Zealand collision data (NZ Ministry of Transport, 2011a, table 7) show that 34% (441 out of 1300) of motorcyclist injuries are serious. If we make the assumption that 34% of injuries in motorcyclist-involved injury crashes are also serious, then it can be shown that the total social costs associated with motorcyclist-involved crashes at urban and open-road junctions is as shown in Table 6.1. It should be noted that this assumption, and several others on which this kind of analysis stands (see below), is tentative. This is because a motorcyclist injury is not the same as an injury collision in which a motorcyclist was involved; sometimes a motorcyclist will be involved in a collision in which someone else (for example a car driver) is injured, but in which they themselves are not injured. Since the injury severity for motorcyclists is likely to be higher than for other vehicle occupants, 34% is likely to be an overestimate of the percentage of injuries in motorcyclist-involved injury crashes which are serious. An added complication is that collisions at open road junctions will tend to involve higher speeds and therefore it is likely that they will be more serious than collisions at urban junctions, all other things being equal. For this and other reasons, the calculations in Table 6.1 are to be treated as indicative only. To make a full judgement on the likely impact of different measures, a full analysis of the costs of different types of motorcycle-involved collision will be necessary.

With all of these caveats in mind, what this analysis seems to show is that urban junctions, by virtue of the far greater number of motorcyclist injury collisions for which they account, may hold a greater potential public health benefit from the introduction of measures to improve motorcyclists' conspicuity in NZ, if considering the social cost data discussed here. In other words it would be sensible to consider those measures that have the potential to work in both urban and rural contexts if possible, but failing that it would be sensible to consider options that seem likely only to work in the urban context ahead of those that seem likely only to work in the rural context. Of course there may be other motivations to introducing measures to improve conspicuity (such as specifically reducing fatal and the most serious injuries), in which case a focus on the higher-speed impacts at open road junctions may be justified.

Table 6-1: Estimated social costs associated with different severities of motorcyclist-involved crash at urban and open road junctions, based on NZ data to the end of 2010

	Urban		Open road	
	Number	Estimated cost ($NZ)	Number	Estimated cost ($NZ)
Minor	307	24,552,000	48	3,801,600
Serious	158	118,416,900	24	18,335,520
Fatal	6	25,932,000	11	47,542,000
Total	471	168,900,900	83	69,679,120

An issue when considering the likely social cost benefits is the day/night split of crashes. Again looking at data for 2010 (NZ Ministry for Transport, 2011b, table 33 excluding pedestrian accidents and miscellaneous), it can be seen that 23.9% of urban road junction motorcyclist injury collisions occur in the hours of darkness (9% of all injury accidents involving motorcyclists), despite the volume of motorcycle traffic at night being likely to be lower than during the day. This suggests that interventions that target night-time accidents specifically (for example Gould et al., 2012) would still have a meaningful impact on collisions if implemented successfully, although interventions designed to work in the day as well would be expected to have a larger benefit overall all other things being equal (due presumably to the greater exposure to risk during daytime).

A further issue related to the New Zealand context is that the law already requires the daytime use of headlamps or daytime running lights for motorcyclists. For cars they are not required, but they are permitted (New Zealand Transport Agency, 2005). If it is anticipated that daytime running lights on cars may become required in New Zealand, or may be introduced *de facto* as more cars are manufactured with such lights, it may be worth considering interventions that are designed to further increase the conspicuity of motorcycles relative to background contexts which include other vehicles with daytime running lights.

In summary, all of the intervention types studied in the literature seem likely to have some impact (if implemented properly) in New Zealand, albeit to different degrees.

6.3 The acceptability of interventions

Another issue not covered within the scope of the main review is the acceptability of the various conspicuity measures that might be proposed. This is an important issue since the public health benefit of any intervention will depend not only on its potential effectiveness but also the extent to which it is utilised by the riding population. There has been some work on this. For example Reeder, Chalmers and Langley (1996) surveyed 18 year old motorcyclists in New Zealand and found that although 55% favoured mandatory wearing of high-visibility clothing, only 15% of day-time and 20% of night-time riders reported doing this. Aitken et al. (2012) investigated the use of, and attitudes to, high-visibility clothing amongst motorcyclists in Wellington, New Zealand. They found that its use was not widespread; observations showed that 38% of motorbike riders and 33% of scooter riders wore no form of high-visibility material on their helmet or jacket. The study identified some positive rider attitudes towards high-visibility clothing but that the common barriers given to wearing the clothing were image, cost, practicality and availability. They also found a prevailing attitude that high-visibility clothing does not improve safety and that it is the other road users who are at fault. Some interviewees described such clothing as 'uncool' and 'non-professional', and that such gear was not thought socially acceptable. A recent study by Rößger et al. (2012) showed that high visibility vests were viewed as less acceptable than a 'T' lighting configuration, suggesting that clothing interventions may be more difficult to 'sell' to motorcyclists than interventions that are built into the machines they ride.

Christmas, Young, Cookson and Cuerden (2009) interviewed motorcyclists in Great Britain, and provide another reminder of the complexity of introducing successful public health interventions. The aim of the study was to understand the heterogeneity present in the motorcycling community. Seven segments were derived from the interviews. These were 'riding hobbyists', 'performance disciples', 'performance hobbyists', 'look-at-me enthusiasts', 'riding disciples', 'car aspirants', and 'car rejecters'. The segments differed in terms of their attitudes to safety gear (as well as in other ways) and the authors conclude that 'motorcyclists' should not be considered as a single entity when any safety intervention is to be proposed, with a wide range of interventions and strategies likely to be needed according to the rider segment identified as the target audience.

6.4 Recommendations

Taking into account the findings of the review, and the issues discussed in this section, and based on our professional judgement, our recommendations to the Motorcycle Safety Advisory Council are as outlined in Sections 6.4.1 and 6.4.2.

6.4.1 Recommended validation study on lighting configurations

In terms of validation activities in New Zealand to gain a better estimate of the likely impact and acceptability of different interventions to New Zealand motorcyclists, the most promising intervention type (and the one on which there is least research in real-world settings) would appear to be physical changes to motorcycle lighting that either lead to greater contrast with the background (especially differentiation of motorcycles from surrounding traffic with lights – for example differently coloured lights that stand out from the white lights typically seen on cars), or that utilise additional lights to increase the visual 'surface area' of the bike, and therefore help not only with detection but also with speed estimation.

The scope and design of such a validation activity will depend on the resources and time MSAC has available to carry out such work, and on other factors such as whether there is any intention in New Zealand to introduce any specific legislation relating to or impacting on motorcycle conspicuity. For example, if any changes are planned to laws relating to car daytime running lights, then this would need to be accounted for in any validation work. The recent changes to priority movements at junctions in New Zealand would also need to be addressed in any study examining changes over time in collision rates.

For the current purpose of recommending some validation activity focused on lighting configuration changes it is useful to define three possible studies that could be run using different outcome variables, depending on the scale of change anticipated by MSAC in behaviours in the wider population. These three possible studies are described in Table 6-2.

Table 6-2: Three possible studies to validate novel lighting configurations

Study title	Summary and scope
The effect of novel motorcycle lighting configurations on self-reported behavioural responses by motorists at junctions	The study would examine several novel motorcycle lighting configurations and, in an empirical study, would measure their impact on self-reported behavioural responses at junctions. The precise lighting configurations would likely include: • ‘Tri-headlight’ (Gould et al., 2012) • ‘Helmet lamp’ (Pinto & Cavallo, 2011) • ‘Yellow lamp’ (Pinto & Cavallo, 2011) The study would test at least 300 participants, who would be invited to view a junction with various vehicles passing, some of which would be motorcycles with the different lighting configurations (a bike with the standard lighting configuration would serve as the comparison). Participants would initially be asked to commentate on things that attract their attention (a measure of attention conspicuity), and later would be asked specifically to report motorcycles present in the scene (a measure of search conspicuity). Finally, participants would be asked to indicate the last point at which they would choose to accept a gap in front of the approaching motorcycles (a measure of their ability to appraise time to arrival). The outcome of this study would be a relative assessment of the increases in conspicuity (in terms of distance at which bikes are detected) and an indication of any changes in gap sizes accepted in front of motorcycles with the different lighting configurations. Such a study would be valuable as it add to the current evidence base using real-world data, and would probably attract considerable media attention, possibly aiding in rider acceptability of the planned interventions.

<table>
<tr><th>Study title</th><th>Summary and scope</th></tr>
<tr><td>The effect of novel motorcycle lighting configurations on observed behaviour by motorists at junctions</td><td> The study would be of the same basic design as the first study described above, testing some or all of the same lighting configurations. The study would use more ecologically valid measures however (but possibly more variable, meaning more participants may be needed) and in naturalistic situations. Drivers would be observed in their everyday driving at junctions while motorcycles with the different lighting configurations were being ridden past. At least two measures would be used: Gap size accepted in front of motorcycle – this measure would be used as an indication of how accurately the time to arrival of the motorcycle could be judged.
'Near-miss' pull-outs – occasions on which drivers appeared to 'nearly' pull out into a gap that is clearly too small only to stop themselves at the last minute; this would be used as an indication of failures of detection. Again the outcome of the study would be data on the relative changes in behaviour associated with the different lighting configurations </td></tr>
<tr><td>The effect of novel motorcycle lighting configurations on collisions at junctions</td><td> A final approach would be to run a study examining the impact of any large scale changes in behaviour (for example those associated with changes in legislation) on official New Zealand crash statistics. Such a study would involve statistical modelling and analysis of collision data (mapped to specific junctions) and would also involve assessments of the prevalence of interventions under examination (for example, the number of riders riding motorcycles with newly legislated lighting configurations) and measures of exposure. </td></tr>
</table>

It should be noted that variations on the themes outlined in Table 6-2 are also possible. Different types of roads, day and night time trialling, and traffic flow are all additional variables that might be considered. However these options are offered here to illustrate the kinds of study that might be suitable, depending on the precise study aims.

6.4.2 Raise awareness of potential (and limitations) of high visibility and reflective clothing

The lowest priority for validation would appear to be the use of high-visibility jackets and other clothing. The literature suggests that these are generally effective, but in principle (unlike lighting interventions) they do not appear to offer the same day *and* night effectiveness; even reflective materials require car headlights to be shining on them to be effective at night, and this is not always the case in practice at junctions, especially when car headlights are dipped.

As a general principle, however, MSAC should continue to encourage riders to wear clothing that is inherently highly visible, reflective if possible, and clean, when riding. If awareness campaigns are used to this end they should focus on two things. Firstly, riders should be encouraged to wear bright and reflective clothing by default, on the grounds that this will often make them more visible to other road users. Secondly, riders should be made aware of the inherent limitations of any aid to visibility or conspicuity; special attention should be paid to making riders aware that there is no ‘one-size-fits-all’ solution (for example because of different contrasts with backgrounds) and that even if they have been seen by a car driver waiting at a junction, this does not mean that the car driver will have appraised their approach speed accurately (especially at night).

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'Conspicuity' cartoon reproduced with the kind permission of Martin Honeysett.

Special thanks are due to Cris Burgess for reviewing an earlier draft of this report. During the period of time when reviewing the draft, Cris was riding his motorcycle to work and was struck from behind by a bus. Thankfully, Cris sustained only minor injuries in the collision. The irony of the fact that at the time of the collision he was wearing a bright orange high-visibility jacket, and riding a motorcycle with daytime running lights, is not lost on the authors.

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