Psychological factors affecting the safety of vulnerable road users:

A review of the literature

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ABSTRACT

We review the psychological factors affecting the safety of vulnerable road users (VRUs – i.e., pedestrians, bicyclists, and motorcyclists). The three VRU groups are considered separately before we draw together common themes that apply to all VRUs and make some recommendations for safety practice based on this synopsis of the literature. The causes of accidents are relatively diverse, but two psychological factors cut across the three VRU groups: (1) drivers often expect only to meet motor vehicles at junctions and so develop habitual attention strategies whereby they do not attend to VRUs and the parts of the road where VRUs tend to be present, and (2) VRUs are not always properly aware of their own vulnerability and so do not always act appropriately to protect themselves. Overall, however, the literature on human factors in VRU safety is still relatively patchy, especially for pedestrians. We therefore conclude with a call for more research on accidents involving these groups.

Keywords: vulnerable road users, bicyclists, pedestrians, motorcyclists, attention, road safety, junctions, intersections

Psychological factors affecting the safety of vulnerable road users: A review of the literature

Three groups of road users stand out from the rest because of their much greater capacity to receive injury than to inflict it: pedestrians, bicyclists, and, to a slightly lesser extent, motorcyclists. 17,000 of these people are killed each year in the European Union, at rates of around 7000 pedestrians, 3000 cyclists, and 7000 motorcyclists. This means that these vulnerable road users (VRUs) account for around a third of all road deaths (Otte, 2002). In other parts of the world the problem can be even worse. Research from Brazil, for example, found that these three groups made up 77% of road injuries and 82% of deaths (de Andrade & Jorge, 2000; see also Ribbens, 2003).

This paper will review the literature on the safety of VRUs. Our hope is that this summary will help drivers, VRUs, and traffic management professionals be more aware of the issues and thereby work more effectively to remedy them (Bergman, Gray, Moffat, Simpson, & Rivara, 2002). The scope of the review will encompass all *psychological topics* which are *unique to the issue of VRUs*. These criteria mean the exclusion of several factors which undoubtedly affect VRU safety – excessive speed, alcohol, and aggression are three that come immediately to mind (see also Rothengatter, 1997). However, factors like these are either not psychological or they affect all road users, and so are not considered here.

Pedestrians

An accident between a pedestrian and a motor vehicle will more often than not be the fault of the pedestrian, at least inasmuch as societies prioritize vehicular traffic over pedestrian and so place the burden of collision avoidance on the walker (Carsten, Sherborne, & Rothengatter, 1998; Roberts & Coggan, 1994). Simoncic (2001), in a study of VRU accidents in Slovenia, found that improper actions from pedestrians were associated with accidents at an odds ratio of 1.24. In the United States, Preusser, Wells, Williams, and Weinstein (2002) found that in accidents between a pedestrian and a motor vehicle, the pedestrian was at fault about as often as the driver was. This was an improvement over previous American analyses, largely because of a reduction in the number of children running out into the road. Accidents where the pedestrian is culpable are mostly caused when people cross the road away from official pedestrian crossings (Al-Ghamdi, 2002; Haruff, Avery & Alter-Pandya, 1998; Preusser et al., 2002).

However, when we try to understand the causes of these accidents by looking at the psychology behind them, we find that research on pedestrian-initiated collisions has mostly been descriptive and epidemiological rather than exploratory, and so although the high incidence of alcohol in pedestrian casualties suggests that psychological factors must be involved (Fontaine & Gourlet, 1997; Harruff et al., 1998; Öström & Eriksson, 2001; Pedden et al., 1996), exactly what these factors are remains largely unexplored. Assuming that pedestrians generally do not wish to be hit by cars, it seems probable that most accidents will be caused by misjudgements of cars' velocities or distances (Hills, 1980), or failures to perceive cars, either because of obstructions (Schofer et al.,

1995) or because of attention failures. Whether the ability to judge distances or velocities is related to pedestrian accident-proneness has not yet been investigated. However, there is a little support for the supposition that attention is involved in pedestrian-initiated accidents. Tabibi and Pfeffer (2003; see also Dunbar, Hill, & Lewis, 2001) found a correlation between a child's general level of attention and their ability to find a safe crossing place, although this might be an artefact of children with poor attention concentrating on the experimental task less (Demetre et al., 1992), especially as there was no relationship between the two abilities in adults in that study (see also Whitebread & Neilson, 2000). Similarly, Oxley, Fildes, Ihsen, Charlton, and Day (1997) suggested that attention was a key factor in older pedestrians' difficulties with complex traffic situations. However, given that all the above studies have looked at subgroups of pedestrians which might reasonably be expected to have poorer cognitive abilities than the norm, further work is still needed to explore whether attention or perceptual failures are indeed involved in general (as opposed to child and elderly) pedestrian-initiated collisions.

The only other aspect of pedestrian psychology that has been examined to any real extent is the pedestrian's *awareness of vulnerability*. This is important for people's safety because they can only respond appropriately to dangers if they are properly aware of them (e.g., Trimpop, 1994). However, it seems that pedestrians for various reasons do not always realize the dangers they face. They greatly overestimate how visible they are to motorists (Allen, Hazlett, Tacker, & Graham, 1970), and even more seriously, it seems that people can forget they are pedestrians altogether. Fontaine and Gourlet (1997) found that in many pedestrian-initiated accidents (28% overall, rising to 41% in people aged between 16 and 44), the pedestrian had recently left a vehicle or was planning shortly to get into one. In particular, the authors refer to many police reports of heavy goods vehicle drivers who were killed soon after leaving their trucks. The drivers in all these accidents were apparently walking around in the mindset of a motorist, and so continued to act as if they were protected from other traffic (Fontaine & Gourlet, 1997).

Turning now to accidents where the driver rather than the pedestrian was responsible, we find that these occur particularly when a car turns onto a road at a junction and hits a pedestrian who is crossing this new road at a signalized crossing (Preusser et al., 2002; see also Van Houten, Retting, Farmer, & Van Houten, 2000). Most of the time in Preusser et al.'s study, these turns were legal and the pedestrians were likewise being told by the traffic lights that they may cross. As in many European countries, these American drivers were allowed to turn onto a road at the same time as pedestrians were crossing it, provided the drivers then waited for the pedestrians to cross before completing their turn. The accidents were happening because the drivers were failing to notice the pedestrians and so were driving right around the junction without stopping. Given that drivers were failing to spot pedestrians who were crossing the road in their path (and in the left-turn cases, the drivers travelled a considerable distance before reaching the crossing, showing that they had some time to look for the pedestrians), this points to the mechanism behind many accidents being a failure of attention. To date, there has been no research on drivers' attention in collisions with pedestrians specifically. However, we know that drivers' general levels of attention influence their accident-proneness (Goodenough, 1976; Kahneman, Ben-Ishai, & Lotan, 1973). Moreover, there has been quite a lot of research on drivers' attention in bicyclist accidents, and we will suggest in the Discussion section that the bicyclist attention research – as well as work on driver attention in general (Hills, 1980; Moray, 1990) – will also be applicable to the pedestrian case. The Discussion will also describe pedestrian safety interventions whose success further supports the idea that drivers' attention must be involved in these accidents.

Bicyclists

Although bicyclists usually share space with traffic which travels at very different speeds, there is lots of evidence to say that cyclists are safest riding on roads, followed by off-road paths, followed by pavements and shared-use paths (Aultman-Hall & Adams, 1998; Aultman-Hall & Hall, 1998; Aultman-Hall & Kaltenecker, 1999; Garder, Leden, & Thedeen, 1994; Moritz, 1998). This suggests that attention should be focused on making the on-road environment as safe as possible rather than taking cyclists off the road.

Cyclists are even more likely than pedestrians to be the cause of their own accidents. However, whereas pedestrians need the assistance of a motor vehicle to achieve injury, cyclists usually do it by themselves[1]. Studies have repeatedly found that most cyclists who receive hospital treatment do so because of accidents involving no other road user (Aultman-Hall & Hall, 1998; Doherty, Aultman-Hall, & Swaynos, 2000; Moritz, 1998; Langley, Dow, Stephenson & Kypri, 2003; Olkkonen, Lähderanta, Tolonen, Slätis, & Honkanan,

[1] Actually this is a lie. Quite a lot of pedestrians are hospitalized in the absence of motor vehicles (Eilert-Petersson & Schelp, 1998; Stutts & Hunter, 1999), but in nearly all these cases they injure themselves by slipping on ice. The point is that cyclists, *mutatis mutandis*, have the ability to hurt themselves in the normal course of their locomotion in a way pedestrians do not.

1990; Stutts & Hunter, 1999). Despite this, cyclists should still be classified as VRUs in the sense in which the term is generally understood because although most of their injuries are caused by falls in the absence of other road users, these tend to be relatively minor incidents. When we consider deaths and serious injuries, collisions with motor vehicles are nearly always the cause (Atkinson & Hurst, 1983; McCarthy & Gilbert, 1996; Olkkonen et al., 1990; Rodgers, 1995). For the purposes of this review, then, there is a clear need to ask which psychological factors are involved in bicyclist accidents on the road. Most of the relevant studies have focussed on the processes involved at junctions, as these are by far the most dangerous places for cyclists, accounting for 75% of accidents between cyclists and motor vehicles in the UK, for example (Department for Transport, personal communication).

The main identified cause of collisions to bicyclists is a process described in the context of general driver psychology by Hills (1980) and Moray (1990), and more recently in the specific case of bicycling by Räsänen and Summala (1998). People have a highly limited ability to receive visual information, being able to fixate on fewer than three points per second at the very maximum (Moray, 1990). To compensate for this, after more than a few hours' experience of a complex task like driving they develop mental models of what goes on in their surroundings. These mental models – *expectations*, in other words – guide attention to the areas of the surrounding scene most likely to be important. Because a typical driver's encounters are predominantly with motor vehicles, their expectation will usually be that only other automobiles will be present at a junction. This expectation guides their attention to motor vehicles and parts of the road where these might be found and away from cyclists and areas where these tend to be.

An example of this process was seen in Räsänen and Summala's (1998; Summala, Pasanen, Räsänen, & Sievänen, 1996) study of Finnish cycle paths. These often cross roads near junctions and Finnish law states that drivers approaching a junction must yield to a cyclist who is crossing the road, somewhat like the pedestrian crossings discussed earlier. However, accidents are still relatively common. In accordance with this expectation-attention account, Räsänen and Summala found that drivers on many occasions simply did not look towards the cyclist before the collision. The reason for this lack of attention was that the drivers' visual searches were guided by the expectation that only other motor vehicles would be encountered at the junction.

The expectation-attention process is seen even more dramatically in the 'looked-but-failed-to-see phenomenon' (Hills, 1980), whereby even a driver looking in the right direction to see a cyclist might not become consciously aware that the cyclist is there. This most commonly happens with more experienced drivers (Herslund & Jørgensen, 2003), precisely because these are more likely to have habitual search patterns which focus attention in very narrow regions of the visual scene likely to contain motor traffic; regions of space likely to contain cyclists (e.g., the edge of the road) receive less attention (Herslund & Jørgensen, 2003; Hills, 1980; Moray, 1990; see also Joshi, Senior, & Smith, 2001; Mannering & Grodsky, 1995).

Another psychological influence on bicyclist safety is the cyclist's perception of risk. A cyclist will respond to a perceived risk either by taking countermeasures or by adjusting their behaviour. Therefore, the extent to which a cyclist deals effectively with risk will depend on their having an accurate perception of it (Trimpop, 1994). But the evidence suggests that cyclists' risk perceptions are neither accurate nor objective. Osberg, Stiles, and Asare (1998) observed around 6,000 cyclists in Paris and Boston and found that cyclists in the two nations protected themselves very differently, and so were presumably perceiving the risks of cycling differently, or at least were perceiving the efficacy of protective measures differently. In Boston, a good proportion of cyclists (32%) wore helmets whereas in Paris very few did (2%). However, when the researchers looked at the use of lights at night they found a reversal – 47% of Parisian cyclists used lights compared to only 15% in Boston. Differences in local environment might account for some of these variations. For example, Osberg et al. suggest that Parisian drivers are more used to cyclists. However, even if this might explain the French cyclists' feeling less need for helmets, it would not explain their feeling so much more need for illumination at night. As such, the findings of Osberg et al. show that risk perception must be imperfectly correlated with the actual risks, and so it will be another psychological factor affecting cyclists' safety. This factor is similar to the awareness of vulnerability identified in pedestrians (Fontaine & Gourlet, 1997).

The final psychological influence on cyclists' safety is signal perception. This factor has no parallel in the pedestrian literature as pedestrians and motorists are much more segregated. Cyclists, however, share the road with motor vehicles and so the efficacy of cyclists' signals will affect their safety: If a driver misperceives a cyclist's intentions at a junction, there is obvious potential for a collision.

Drury and Pietraszewski (1979) carried out the first study of how well drivers perceived cyclists' signals and showed that both formal signals (arm signals) and informal signals (e.g., trailing a foot when coming to a halt) were read with varying degrees of accuracy, typically with error rates of around 20% for formal arm signals. Walker (in press) carried out a follow-up experiment which revealed that although a cyclist's arm signals generally were easy to perceive and communicated the cyclist's intentions to the driver, they slowed drivers' responses down, leading to an increased likelihood of the driver failing to respond in the thinking time available. Further experiments by Walker and Brosnan (in prep) found that responses to an arm signal were not slowed when the decision was 'is the cyclist going to turn the corner?' but *were* slowed when the decision was 'is the cyclist going to turn *in front of you*? [emphasis added]'. (A control condition showed that this was not because the task was more cognitively demanding.) This means that drivers perceive cyclists' arm signals easily but that relating this information to themselves is time-consuming, leading to slowed reactions. This could of course translate to accidents in real driving situations.

Walker and Brosnan also found an unexpected effect on drivers' responses when the cyclist gave no arm signal but instead looked across a T-junction from the major road to the minor road. First, there were individual differences in how people interpreted this cue: around 20% of drivers interpreted a glance across the road as indicating an upcoming turn whereas the rest did not. Second, reaction time analysis showed that all drivers were particularly slow to respond to this situation. These findings show that there are situations where the cyclist is not intentionally signalling but where their behaviour affects how drivers perceive their intentions. A cyclist can give inadvertent signals which (a) slow drivers' decisions down and (b) lead to individual differences in the drivers' interpretations – with clear potential for accident causation. Further research is now needed to see whether these signals affect driver decision-making in real (rather than experimental) traffic situations, and if so, to see whether VRUs give any other inadvertent signals which drivers erroneously interpret as indicating an upcoming manoeuvre.

Motorcyclists

Motorcyclists are, however we choose to calculate it, more at risk of injury than any other road users.[2] In Britain they make up only 1% of traffic but 15% of the people killed or seriously injured on the roads (Department for Transport, 1999a). A motorcyclist in the US is more than 5 times more likely than a driver to have an accident over a given distance and more than 20 times more likely to be killed (Mannering & Grodsky, 1995). Motorcyclists are the only traffic group in the UK for which the injury and death figures are rising (Lynham, Broughton, Minton, & Tunbridge, 2001; see also Bellaby & Lawrenson, 2001).

As with bicyclists, a lot of motorcyclist injuries involve no other vehicle (estimates of the exact proportion vary depending on which accidents are included, from 18% [Department for Transport, 1999a] to 29% [Lynham et al., 2001]). Most of these accidents involve the motorcyclist running off the road or otherwise losing control of their vehicle, often due to excessive speed (Lynham

[2] The figures given here notwithstanding, Cirera, Plasencia, Ferrando, and Segui-Gomez (2001) found slightly more pedestrians than motorcyclists being admitted to hospital emergency departments over the course of a year in Barcelona, but this is probably an anomaly associated with the region: Spain is among the European Union's worst states for pedestrian safety (Department for Transport, 1999b).

et al., 2001; Preusser, Williams, & Ulmer, 1995). These accidents tend not to happen at junctions and are obviously more serious than the self-induced accidents we mentioned in bicyclists.

When we consider accidents between a motorcycle and another vehicle, on the other hand, which account for slightly more than half of all serious motorcycle accidents, we see that in 60% of cases the motorcyclist was judged to be at fault, with loss of control being the main cause. In the remaining 40% of serious accidents, where the driver of the other vehicle is at fault, failure to give way to a motorcyclist who has priority at a junction and poor manoeuvring are the main causes of collisions (Lynham et al., 2001). As with other VRUs, accidents between motorcycles and other vehicles primarily happen at junctions in built-up areas, particularly so when the other vehicle is a large vehicle (Department for Transport, 1999a; Harrison, 2004; Lynham et al., 2001).

To first consider the psychological factors which contribute to accidents caused by the motorcyclist, we see two different schools of thought. Some researchers suggest that motorcyclists have cognitive or personality factors which make them more dangerous than other road users (e.g., a greater propensity to risk-taking or sensation-seeking or a mindset which consistently underestimates the risks involved) This approach is therefore part of a long-standing safety research tradition of identifying traits which might make some people particularly accident prone (Rothengatter, 1997). Other researchers say that motorcyclists are essentially no different from everybody else on the road, that they estimate the risks of motorcycling appropriately, and that their propensity to cause accidents must therefore be a result of extrinsic factors.

To consider the first school of thought, several people (Bellaby & Lawrenson, 2001; Natalier, 2001; Rutter, Quine, & Albery, 1998; Rutter, Quine, & Chesham, 1995) have argued that although motorcycle riding is objectively dangerous, motorcyclists construct perceptions of risk which downplay the dangers. In particular, these researchers argue, many riders emphasize the idea that the risks come not from motorcycling per se but rather from other road users and from the way roads are constructed and maintained[3] (Bellaby & Lawrenson, 2001). These perceptions of risk are further affected by beliefs about the ability to cope with dangers. Specifically, there is a belief amongst riders that the dangers of motorcycling can be ameliorated through riding skill, with a few riders going so far as to claim that *every* accident could be avoided if the rider were skilful enough (Bellaby & Lawrenson, 2001; Natalier, 2001; Trimpop, 1994). Driver research has consistently found that people overestimate their own ability compared to the perceived average (Groeger & Grande, 1996; Horswill, Waylen, & Tofield, 2004; McKenna, Stanier, & Lewis, 1991; Walton & Bathurst, 1998), and so an overoptimistic perception of one's ability to cope with risk could plausibly be a factor in motorcycle accident causation (although whether any misjudgements of ability actually translate into accidents appears not to have been explicitly assessed).

As well as looking at risk perceptions, researchers have sought personality factors in the motorcyclists which might make them more likely to have accidents (Chesham, Rutter, & Quine, 1993; Reeder, Chalmers, Marshall, & Langley, 1997). Schutz, Gresch, and Kerwien (1991, reported in Lynham et al., 2001) claim that a major motivation for motorcycle riding is risk-taking and

[3] For example, manhole covers and diesel spills can easily make two-wheeled vehicles skid, but do not affect four-wheeled vehicles.

sensation-seeking. Jackson and Wilson (1993) identified these same traits as characteristics of motorcyclists and Lin, Chang, Pai, and Keyl (2003) recently found an association between a risk-taking personality factor and motorcycle accidents in a large sample of Taiwanese students (see also Turner & McClure, 2004). Reeder, Chalmers, and Langley (1996) found that young men in New Zealand often cited excitement as a reason for motorcycling.

Contrary to all the above research, however, other studies have failed to find any personality differences between motorcyclists and drivers (Horswill & Helman, 2003; see Reeder et al., 1997, for a review of earlier work). For example, Leaman and Finch (1987) found no evidence of impulsiveness being related to the likelihood of a motorcyclist having an accident. Mannering and Grodsky (1995) largely dismissed the idea that motorcyclists misperceive the risks of their activity and Trimpop (1994) pointed out that motorcycle accidents are more likely during utility journeys than during recreational journeys, in which the motorcycling is an end in itself. If risk-taking is part of the appeal of motorcycling, we might reasonably expect to see more accidents in recreational motorcycling rather than when it is simply a means to an end. (This final point must be interpreted with caution, however, since Trimpop's analysis is made without reference to the relative number of utility and leisure journeys that are made.)

Recent work by Horswill and Helman (2003) provides some clues for how we might resolve these two approaches to motorcyclists' accidents. This study again found that motorcyclists were more 'risky' than drivers in that, for example, they entered smaller gaps in traffic and overtook cars in less forgiving situations than drivers did. Crucially, however, these behaviours were only seen when the motorcyclists were on motorcycles; they acted just like non-motorcycling drivers if they were in cars. This suggests that the 'dangerous' behaviours mentioned in many studies, such as entering small gaps in traffic, might not really be dangerous when the abilities of the motorcycle are taken into consideration (Horswill & Helman, 2003). More generally, this suggests that any factors predisposing motorcyclists to certain behaviours are situation-specific, and that in order to assess them in motorcyclists, researchers need to put the motorcyclists into a motorcycling mindset. Studies which found motorcyclists to be more risk-taking and sensation-seeking using general measures of these traits rather than specific measures (e.g., Jackson & Wilson, 1993; Lin et al., 2003; Turner & McClure, 2004) were perhaps not tapping the aspects of risk-taking and sensation-seeking that are actually relevant to motorcycling behaviour.

To help resolve the issue, we tentatively suggest that general risk-taking measures of the sort used by Jackson and Wilson (1993), Lin et al. (2003), and Turner and McClure (2004) were predicting the likelihood of somebody taking up motorcycling but not really predicting the safety of their riding once they had done so. Specific motorcycle-based measures will be needed for this (Horswill & Helman, 2003). Moreover, as we have seen, the studies which have done this have found that motorcyclists do not appear particularly likely to take unwarranted risks or otherwise have unusually dangerous personalities (Horswill & Helman, 2003; Leaman & Finch, 1987; Reeder et al., 1997; Trimpop, 1994). This implies that many of the accidents judged to be the motorcyclists' fault might more properly be attributed to extrinsic factors such as engineering design (overpowered bikes, roads appropriate for driving rather than motorcycling) and other people's behaviour. On the other hand, Natalier (2001) and Bellaby and Lawrenson (2001) showed that motorcyclists are clearly aware of these issues and also attribute most accidents to these causes, and so the question remains as to why they do not better adjust their behaviour to account for these dangers.

Moving on to driver-initiated accidents (which have been studied rather less), failures to give way to the motorcyclist were the most common type of serious accident, usually occurring at T-junctions and crossroads (Lynham et al., 2001). Lynham et al. report that these occurred most often when a vehicle travelling on the left-hand side of the road (as is normal in Britain) turned right, across the carriageway dedicated to oncoming traffic, without seeing or yielding to the oncoming motorcyclist. Alternatively, drivers pulled out onto a major road from a minor road without seeing or yielding to the motorcyclist on the major road. Notably, Stone and Broughton (2002) and Atkinson and Hurst (1983) identified these same two situations as the most frequent types of collision between cars and bicycles, which suggests that drivers are probably hitting bicycles and motorcycles for the same reasons. The similarity between the circumstances of bicycle and motorcycle accidents was also noted by Otte (2002). We suggested in the bicyclist section that the cause of such accidents is often a failure of attention caused by drivers' expectations of what they would encounter at junctions. A similar mechanism is therefore likely to be at work in motorcyclist collisions (Mannering & Grodsky, 1995), given that drivers reported often not having seen the motorcyclist before a collision (Lynham et al., 2001).

DISCUSSION

Pedestrians, bicyclists, and motorcyclists – in that order – are the groups most likely to be hurt by other road users (Mayou & Bryant, 2003). This paper has drawn together research on the psychological factors behind collisions to these groups and has also considered the factors that dispose them to hurt themselves. Clearly, there are many influences on vulnerable road user (VRU) safety and there will be no single answer to why accidents happen (Hills, 1980), especially as there are differences between the three types of VRU. However, we can still identify some common themes across the studies we have reviewed and so tentatively extract lessons for accident prevention.

Perhaps the most important theme to emerge across the three VRU groups is the finding that junctions are a particular danger spot because drivers fail to yield when they should. Pedestrians were struck by turning drivers who should have seen the pedestrians and stopped (Preusser et al., 2002). Bicyclists were struck by drivers who should have stopped to allow the bicyclists to cross in front of them (Leden et al., 2000; Räsänen & Summala, 1998; Stone & Broughton, 2002; Summala et al., 1996). Motorcyclists were also struck by drivers who cut across their paths when they should have stopped and waited (Lynham et al., 2001).

Of course, in many ways it is not surprising that accidents happen at junctions. Roads are designed so that normally, traffic flows smoothly and road users have no real decisions to make. This changes at junctions, where vehicles have more opportunities to collide and where people must attend to multiple sources of information and interpret their own plans in relation to the perceived intentions of others. However, VRUs are hit at junctions more than automobiles are, showing that there is something unique to VRUs which puts them at particular risk there.

So just what is it that causes vehicles to hit VRUs at junctions? In summarizing the literature we have found that for each type of VRU, at least one researcher has noted the same general principle: to compensate for limited information-processing capacity, drivers form expectations of what they will encounter on the road and use these to guide their attention. These expectations often predict that only cars and other such vehicles will be encountered (which, statistically, is a reasonable assumption in many environments). As a result, drivers attend only to motor vehicles and regions of space in which motor vehicles are found. The drivers thereby often overlook places where VRUs might be present and so fail to spot the VRUs (Hills, 1980; Moray, 1990; and Räsänen & Summala, 1998, described this mechanism most explicitly, but see also Atkinson & Hurst, 1983; Herslund & Jørgensen, 2003; Joshi et al., 2001; Mannering & Grodsky, 1995; Preusser et al., 2002; Summala et al., 1996; Van Houten et al., 2000).

Interestingly, Jacobsen (2003) and Leden (2002; Leden et al., 2000) found that across several different countries and several different decades, as levels of pedestrian and bicyclist activity in a community rose, the per capita risk for pedestrians and cyclists fell (on average, 100% more VRUs led to only 32% more accidents). Jacobsen states that this effect must come about because drivers "adapt their behavior in the presence of people walking and bicycling" (p. 205). Given the research we have reviewed, the mechanism behind this adaptation seems likely to be a change in drivers' expectations: drivers become aware – probably implicitly – that they are more likely to encounter VRUs and so pay greater attention to VRUs and the regions in which VRUs might be present.

Given the expectation–attention account we have discussed, what are the lessons for accident prevention? First, assuming we cannot change drivers' behaviour by greatly increasing the numbers of VRUs on the road (Jacobsen, 2003; Leden, 2002), junctions might be (re)designed such that VRU safety does not rely on drivers spontaneously spotting the VRUs. One way of doing this is to use external cues which guide drivers' eyes towards regions where VRUs might be present. Summala et al. (1996) tested this method and showed that physical measures such as signs were reasonably effective in making the drivers look towards the Finnish cycle paths more often (see also Leden, Gårder, & Pulkkinen, 2000; Van Houten & Retting, 2001; see also the different physical intervention tested by Dixon, Alvarez, Rodriguez, & Jacko, 1997). However, the drivers in Summala et al.'s study still only looked at the danger area 31% of the time (see also Harré & Wrapson, 2004). And more importantly, the looked-but-failed-to-see research suggests that simply making drivers glance in the right direction is not enough to ensure that VRUs are safe (Herslund & Jørgensen, 2003). Moreover, this solution still relies on the driver acting appropriately even if they do perceive the VRU (Van Houten et al., 2000). Therefore a better solution seems to be to arrange roads such that there is far less reliance on attention being focused in exactly the right place at exactly the right time. In a system like a roundabout (Herslund & Jørgensen, 2003), T-junction, or one of the crossings which take pedestrians or cyclists across junctions (Preusser et al., 2002; Summala et al., 1996), it is too demanding for drivers to attend to regions that might contain motor vehicles *and* regions that might contain VRUs (Hills, 1980; Moray, 1990). Two potential solutions therefore suggest themselves: education and segregation. First, education: drivers can be better warned of where to look for VRUs near junctions. As well as this, and probably more usefully, VRUs can be encouraged to put themselves in the very places that drivers naturally look. For example, on roundabouts and at other junctions, cyclists can position themselves in the centre of their lane, where a motor vehicle would be, rather than keeping to the side of the road where, as we have seen, drivers often do not look. This is already the advice given to cyclists by many training practitioners (e.g., Ballantine, 2000; Franklin, 1997). The studies reviewed here provide these trainers' practical experience with empirical justification. Atkinson & Hurst (1983) reached a similar conclusion after analysing accident data from the United States and New Zealand.

Second, segregation. This can take two forms. First VRUs could be removed from the environment of cars. However, this is for several reasons an undesirable solution. For example, off-road tracks and shared-use paths are even more dangerous places for cyclists to travel than roads (Aultman-Hall & Adams, 1998; Aultman-Hall & Hall, 1998; Aultman-Hall & Kaltenecker, 1999; Garder, Leden, & Thedeen, 1994; Moritz, 1998). Moreover, it is probable that any segregated route for pedestrians or cyclists would increase journey times, which would act as an unfortunate disincentive in societies that want to get more people cycling and walking for the health and environmental advantages that these offer (Hillsdon & Thorogood, 1996; Lawlor et al., 2003; Mutrie et al., 2002; Ogilvie, Egan, Hamilton, & Petticrew, 2004).

Instead, segregation might take a gentler form, in which motorists and VRUs mix, but in more predictable ways than at present. For example, when a driver travels through an intersection, they might be required *always* to stop for VRUs during the manoeuvre or *never* to stop. Situations such as those examined by Preusser et al. (2002), Räsänen and Summala (1998; Summala et al., 1996), and Van Houten et al. (2000), where drivers sometimes have to stop and sometimes do not, depending on whether VRUs are present, are probably best avoided because they rely on the driver's attention always working to spot the VRUs, which clearly does not work. These systems are found in the United States and many parts of Europe. However, one place they are not found is in the United Kingdom. There, when pedestrians (and, sometimes, cyclists) are told by a signal that they can cross a road, they know that all vehicles in the vicinity are held in place by red lights and that nothing should come around a corner. Similarly, when drivers have a green light, they know there should be no VRUs anywhere in the road ahead. It would be useful explicitly to compare the UK with another country to see whether this increased predictability and simplicity really works to protect pedestrians. If so, the principle could be extended to other countries, and to other VRU situations.

Other techniques have been tested for protecting VRUs at junctions. To return to the pedestrian crossings where drivers must pause part-way through their manoeuvre if they encounter somebody walking across the street, Van Houten et al. (2000) tested a system where the pedestrians were given a 3-second head-start before cars were given a green light. This greatly reduced the number of conflicts between pedestrians and motorists. Presumably, given the expectation–attention model we have discussed, the system worked because by the time motorists rounded the corner, the pedestrians were in the middle of the road, where drivers focus their attention. This is similar to the bicycle safety advice mentioned above, which similarly identified being in the middle of the carriageway as safer.

But if we are arguing that pedestrians and cyclists are more likely to be seen by drivers if they are in the middle of the road, this begs the question: are motorcyclists not there already? The answer is yes and no. Motorcyclists do sometimes exploit the extra manoeuvrability of their vehicles and in doing so put themselves towards lane edges and other places that drivers do not expect to encounter traffic. But more importantly, exponents of the expectation–attention theory have claimed severally that because drivers have "conditioned themselves to look only for other automobiles as possible collision dangers" (Mannering & Grodsky, 1995, p. 21; Hills, 1980), motorcyclists are overlooked because of looked-but-failed-to-see mechanisms. Clearly, being in the middle of a lane helps VRUs be seen but is by no means a guarantee that this will happen.

Attention, as we have discussed it here, is a mechanism which lies outside the VRUs and causes accidents to happen *to* them. However, a second factor has been identified in all three VRU groups which, unlike attention, resides within the VRUs and leads *them* to cause accidents. This factor is the road user's awareness of vulnerability. Fontain and Gourlet (1997) and Allen et al. (1970) showed that pedestrians often do not properly understand their vulnerability. Osberg et al. (1998) showed that cyclists cannot be objectively aware of the risks they face, as different people take different safety precautions to the same threat. Various studies of motorcyclists have claimed that their awareness of vulnerability is imperfect (Trimpop, 1994). Awareness of vulnerability is a factor often cited in the traffic psychology literature, usually in relation to the concept of risk management strategies such as risk homeostasis (e.g., Simonet & Wilde, 1997; Trimpop, 1994; see also Rothengatter, 1997). Under such accounts, if risk perception is skewed such that risks are underplayed, behaviour will tend to become more dangerous. Therefore, if it is true that VRUs do not always have proper perceptions of their vulnerability, or of the efficacy of precautionary actions, we can reasonably expect this to be another factor in accident causation (Trimpop, 1994).

CONCLUSIONS

Accidents affecting vulnerable road users (VRUs) show a considerable amount of variability. Most fundamentally, accidents which happen *to* VRUs have different causes to accidents caused *by* VRUs. Accidents caused by VRUs differ considerably from pedestrians to bicyclists to motorcyclists, and in the case of bicyclists and motorcyclists often do not involve another vehicle. We have suggested that a common factor across the three groups is the VRU's awareness of their own vulnerability.

In accidents where a VRU is struck by a vehicle, the literature suggests that many incidents occur because drivers expect only to interact with other automobiles and so attend to their surroundings in such a way that VRUs are overlooked (Hills, 1980; Joshi et al., 2001; Mannering & Grodsky, 1995; Moray, 1990; Räsänen & Summala, 1998). This is perhaps most dramatically seen in the looked-but-failed-to-see phenomenon, where drivers do not expect to encounter VRUs and so do not become aware of VRUs even though they look at them (Herslund & Jørgensen, 2002; Hills, 1980).

There is evidence that the danger for VRUs goes down considerably as the number of VRUs in an area increases (Jacobsen, 2003; Leden, 2002; Leden et al., 2000). However, in many areas of VRU safety – particularly with regard to pedestrians – data are still scant and more work is urgently needed on the human factors responsible for accidents (Jacobsen, 2003; Langham & Moberly, 2003).

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