The Human Element

Alexandra E A Luck BSc (Hons), MSc, MCHIT, MEWI

A Luck Associates

ABSTRACT

It is recognised that road user error, either alone or in combination with environmental and/or vehicular factors is responsible for the vast majority of collisions. Errors are regularly made by people when on the highway, either unintentionally or because they are not able to perform their tasks as a road user as they should. In addition, people are not always prepared to comply with the rules of the highway, and intentionally violate them. However, the highway, with all the assets which it encompasses, has an important role to play in road safety. The manner in which the highway is managed and the way it relates to, and makes sense in light of the environment by which it is surrounded, can make these unsafe actions performed by road users more or less likely. By tailoring the design and operation of the highway infrastructure to take into consideration human cognitive capacities and limitations, those parts of the system which result in human errors or traffic violations are, as far as possible, prevented. Highway condition can assist or hinder the user, and its infrastructure can increase or decrease the severity of the outcome when an incident occurs, by the extent to which they take into account human physical vulnerability. Of course, this is not to rule out the very significant contribution of vehicle design and role of road user education; the key principle is that the responsibility for road safety is shared between everyone.

1 THE CONTRIBUTORY FACTORS TO ROAD TRAFFIC COLLISIONS

It is recognised that most collisions have a number of contributory factors which may be a combination of human, environmental and vehicular failings or defects. A report produced by Sabey and Taylor (1980) summarised the findings of two studies into the role of the road, the vehicle and the road user in collision risk. It was found that the road user was the sole contributor in 65 percent of collisions, whereas road and vehicular issues were each the sole contributors in only 2.5 percent of collisions and were much more likely to be to be linked with a human factor. The road and human error contributed to 24 percent of collisions, while the vehicle in combination with a human factor was judged to be the causation in only 4.5 percent of the collisions analysed. Examination of all the different combinations found the total percentage contributions were: 94.75 percent for human factors; 28 percent for road environmental factors; and 8.5 percent for vehicular factors.

Percentages around these values are still accepted within the UK today and are not infrequently cited by people in the field of engineering to explain the feeling that there is a limit to the amount of further collision savings which can be made through management and design of the highway.

In this context, errors can be defined as behaviours which are inappropriate for the situation in which they are performed, and may arise from unintended or intended actions. Unintended actions which lead to errors can result from failures of perception or attention. Intended actions, for example risk-taking behaviours, and mistakes, resulting from a failure of judgement in selecting the correct behaviour, are also associated with involvement in road traffic collisions.

In order to improve safety in a sustainable manner we have to accept that, given the complexity of the tasks we are required to perform within the road environment, the limitations of human cognitive capacity makes the road user fallible, and the manner in which we assess risk means that we will not always obey rules. By taking this into consideration in how we design and manage the highway and its surrounding environment, we are better able to lessen, as much as is possible, the likelihood that errors will occur, and when they do, by combining this with an understanding of human physical vulnerability, reduce the severity of the outcome.

2 HUMAN ERRORS – UNINTENDED ACTIONS

2.1 FAILURES OF PERCEPTION

2.1.1 The Visual System

Our eyes detect the presence of light which, when focused on the retina, causes changes in the electrical activity of the neurons located in this inner lining of the eye. The resulting information is sent through the optic nerve to the rest of the brain.

The human eyes perform three types of movement: vergence movements, saccadic movements, and pursuit movements. Vergence movements are cooperative movements which keep the image of the target object on the corresponding parts of the two retinas. In much of normal vision we are scanning a scene in front of us, whether that is a relatively limited one, for example when we read, or the wider surrounding environment to enable us to move around. This scanning comprises brief fixations, linked by eye movements, or saccades, during which the eyes will move as fast as they can. An involuntary change of fixation can be caused by a potentially important change in the scene. Alternatively we can choose to move our eyes to a new location in the scene, where we believe it profitable to look. A pursuit movement occurs when we focus on and track an object, and is the only time we are able to control how fast our eyes move.

The amount of light which enters the eye is controlled by the size of the pupil, an opening in the iris. In low light conditions the size of the pupil increases to permit more of the light available to enter and reach the retina. The shape of the lens which is situated behind the iris, is controlled by ciliary muscles attached to it and enables the eye to focus on objects close to the retina, or far away from it.

The retina contains approximately 120 million rods and 6 million cones, collectively known as photoreceptors or light-sensitive cells. Cones provide high resolution, colour vision, and are responsible for much of our vision in conditions where there is good ambient light. They are most numerous in the fovea, or central region of the retina, which is responsible for our most acute vision, with approximately 60 per cent of the total number of cones lying within the central 20° of the visual field. Cones decrease in number and regularity towards the periphery of the retina. Rods are absent from the centre of the visual field and are most numerous 10 to 15° either side of the fovea. Like cones, they also decrease in frequency as the distance from the central visual field increases. Rods provide monochrome, low resolution vision but are more sensitive to light than cones, therefore in very dim light conditions we are still able to see, although we cannot see in colour and are unable to gather high levels of visual detail about our surroundings.

Bipolar cells form synapses both with the cones and with horizontal cells, cells which span across the cones and combine the inputs from each. Different bipolar cells form synapses with rods in the retina. Ganglion cells receive information both from the photoreceptors via the bipolar cells and amacrine cells, the latter being similar to horizontal cells, working laterally to gather information from a number of bipolar cells. It is the ganglion cells which are responsible for carrying visual information through the optic nerve to the rest of the brain.

A ganglion cell in the centre of the fovea may be connected to only 1 or 2 cones, but a ganglion cell in the extreme peripheral retina may be connected, via the intermediate cells to hundreds of rods. The greater the pooling of input from photoreceptors, the poorer the acuity due to the loss of information about the precise retinal location of the receptors being stimulated.

For many tasks involving motion, fine detailed information is not always required, it is more important to know the location and extent of objects relevant to our current position. This enables us to be able to drive in conditions where fine details are eliminated, such as in fog when water droplets in the air scatter the available light, reducing contrast. Under low light conditions our detailed, cone-dominated central vision is impaired, but as peripheral vision is affected to a lesser extent, and as this part of the system can allow us to navigate, we still able to travel at high speed. Highway features such as carriageway edge-lining facilitate peripheral vision, enabling drivers to travel faster than they would be able to in their absence.

When driving we are also able to make use of a product of our visual system known as depth of focus. This means that when the eyes are focused at a given distance, there is a range of objects both further away and closer than this point which are also in focus. This property is dependent on the size of the pupils: during daylight when the pupil is normally small we have a large depth of focus, but when the pupil expands to allow more light into the eye under lower light conditions, the depth of focus decreases. The consequences for the driver depend on the contrast of the important objects in the surrounding environment: if it is high contrast relative to its surroundings it is likely that the driver will still detect it, but low contrast objects, such as a darkly dressed pedestrian, may go unnoticed. The thickness of the lens increases throughout life losing elasticity and reducing the amount of light reaching the retina, therefore issues relating to depth of focus become greater with age.

Moving from an area of high illumination to one of much lower illumination is also problematic for the visual system. At any particular time we are only able to see within a particular illumination range. Changes in lighting beyond this require the system alter its response range, a process which takes time. For example, for a driver approaching a length of road overhung with trees on a bright sun-lit day, another road user within this darker area is likely fall outside the illumination range to which is driver’s visual system is adapted, reducing the chances that the other road user will be observed. Further, the retina of a pedestrian or cyclist travelling at night will be better adapted to the lower light conditions than a driver in a vehicle using headlights. This may lead the former to overestimate how visible they are to other road users.

2.1.2 Perception

Visual perception is the result of the brain processing sensory inputs from the visual system, and combining them with knowledge and experience. It is a highly interpretive process, designed for the extraction and enhancement of those features in the environment which are important for survival. It evolved to function at the speed at which we were able to move around on foot, and yet we now require it when we are travelling up to or over 70 mph, to enable us to: judge our own speed and the speed of vehicles around us; estimate our distance from other road users; and provide correct information relating to other important aspects of the surrounding environment.

The construction of the visual system, as discussed above, is one method by which we are able to process enough of the wealth of information present in a scene to enable us to travel through it, generally safely, at speed.

The visual system can also make use of what we already know about the visual characteristics of objects and our surroundings, in other words it uses “top-down” processing (Hole, 2007). Theories in this field suggest that sensory inputs by themselves are not adequate for reliable, correct perception, and therefore we must also make use of the knowledge we have gained to be able to interpret sensory data.

A closely related concept is that information processing relies on schemas. Schemas are defined as cognitive, mental plans that serve as guides for action, and as structures for interpreting information or organized frameworks for solving problems (Reber, 1995). The hypothesis is that a schema allows us predict what is likely to happen and to respond efficiently as a result, especially when undertaking predictive and repetitive activities. Therefore schemas, and the expectations generated by them, could have an important role in what we do, and do not perceive, when processing an array of visual information presented to us in the road environment.

A study by Räsänen and Summala in 2000 (Hole, 2007) found that higher entry speed into junctions tended to be associated with drivers scanning the road which they were about to join in one direction only. The experimenters suggest that at higher speeds drivers attend to the scene around them more selectively, making them rely, to a greater extent, on their expectations as to what will be present and where, using minimal visual cues as a basis for action. Therefore an object may exceed perceptual thresholds but if the encounter is unexpected, it may not be detected in the search patterns of the observer.

2.1.3 Conspicuity

Conspicuity is defined as those characteristics of an object or condition that determine the likelihood that it will come to the attention of the observer. There are thought to be two types of conspicuity, *‘sensory conspicuity’* and *‘cognitive conspicuity’*. The former, also known as object conspicuity or attention conspicuity, refers to the capacity of an object to be detected when an observer is not specifically looking for it. Important factors are: size, the object’s contrast relative to its surroundings, its positioning within the observer’s field of view, and whether or not it is moving. It is therefore based on data-driven, bottom-up processing.

Cognitive conspicuity relates to the capacity of an object to be detected if an observer is specifically looking for it. It is dependent on the information contained by the object and the psychological state of the observer, and is therefore more reliant on conceptually driven, top-down processing.

The two types of conspicuity will not always coincide. A directional sign may have high sensory conspicuity, but for a driver who knows the route, the information it contains is irrelevant, and, therefore, has little cognitive conspicuity. While, in such a case, the sign is clearly present in the driver’s field of vision, it may not even reach the driver’s conscious awareness, or in other words, it is not perceived due to its lack of relevance.

Further, even when an object has a high level of sensory conspicuity, a driver must correctly interpret what they are seeing to be able to detect the object and take any necessary action early enough. There are a number of incidents where highly conspicuous vehicles, for example police cars, recovery trucks and traffic management vehicles, parked on high speed roads are struck by drivers who state that they have not seen them until it was too late. Laboratory experiments by Langham, Hole, Edwards and O'Neil in 2002 (Hole, 2007) found that drivers were slower to respond to cars parked in-line than at an angle, an effect that became more marked when the driver was required to perform a simulated mobile phone task at the same time as detecting hazards in the road in front of them. The experimenters thought it possible that driving on high speed dual carriageways is generally a fairly monotonous activity, and one that does not place great demands on the driver. The behaviour of traffic within the same carriageway is reasonably predictable and therefore requires only a cursory and intermittent examination. A single stationary vehicle within a traffic lane is not often encountered and therefore a driver may make an assumption that it is moving in the same direction as themselves until the cue of the radial expansion the vehicle's image on the driver's retina tells the driver that the contrary is actually the case.

2.2 FAILURES OF ATTENTION

Due to the constraints of our visual systems, in order to correctly perceive important objects and information in the road environment, our attention must be directed to parts of the environment in turn. Attention determines not just what we see, but how we see it, restricting how much can reach our consciousness awareness at any given moment.

Attention can be stimulus-driven: bottom-up, external cues in the environment such as sudden movement or noise will generally result in the automatic, involuntary capture of attention. However, attention can also be goal-driven, directed voluntarily and consciously to somewhere of interest or where it is profitable to attend. While the abrupt onset of a stimulus will usually capture attention, overriding top-down influences, this will not be the case if the driver's attention has already been focused elsewhere, before the stimulus' onset.

On-road studies looking at the fixation patterns of novice and experienced drivers have found consistent differences in the duration and spread of fixations between the two groups (Hole, 2007). Experienced drivers increased both the vertical and horizontal spread of their fixation locations on dual carriageways, compared to single carriageway urban and rural roads. Fixation durations were shorter on more demanding roads, potentially enabling the more experienced driver to sample information from more of the surrounding scene. These behaviours suggest that the visual strategies of experienced drivers are based on the complexity of the road and surrounding environment. On the other hand the fixation behaviour of novice drivers showed little variation regardless of the complexity of the road being driven, concentrating on the area that looked most novel, dangerous, or difficult to process. Novice drivers are therefore more at risk of failing to notice the abrupt onset of a stimulus outside the area of the road upon which they are already concentrating.

What a driver looks at will also depend on the circumstances at that particular time. In an uncomplicated environment with little or no traffic, glances are recorded over a wide area (Olson et al., 2010). These decrease as traffic density increases and once a driver is following a vehicle, the glances will narrow still further. The less the separation distance between the two vehicles, the greater the proportion of glances which are directed towards the vehicle in front.

A study by Shinoda, Hayhoe and Shrivastava in 2001 investigated top-down influences on the allocation of attention (Hole, 2007). Using a driving-simulator, participants drove around a computer-generated town. Half of the participants were asked to maintain a constant distance behind the vehicle in front, while the other half were required to perform the same task at the same time as observing normal traffic regulations. During the drive a no parking sign briefly changed to a stop sign which was either located before a junction or in the middle of the street. Shinoda et al. found that the probability of detecting the sign change depended heavily on the participants' task and the sign's location. When just following the car in front, participants rarely noticed the sign change when it was located in the middle of the street or at the junction. When participants had also been asked to observe traffic regulations, they were more likely to detect the change. However, while all those participants noticed the change when the sign was located at the junction, only a third noticed it when it was in the middle of the street. The experimenters concluded that the visibility of traffic signs depends on the driver undertaking active search processes, and that the success of these processes depends on both the observer's goals and on learnt probabilities about the environment.

However, we can also suffer from inattentional blindness. In other words, people can be fixating directly two sets of stimuli, but if attending directly only to one, they can be unaware of the other set even, if they are spatially overlapping and present in the central vision for a prolonged period of time. This has been demonstrated in a number of laboratory studies based around the experiments carried out by Niesser and Becklen in 1975 (Hole, 2007). Participants were asked to watch to a basketball game, attending to the actions of one team only. During the course of the game a man in a gorilla suit or a woman with an open umbrella walked through the game. Between a third and a half of the participants failed to notice the event and when the primary task became more difficult, or in other words, the cognitive load on the observers became greater, the number of participants failing to report the event could increase to almost two-thirds.

It has already been mentioned that our attention may not be captured by the onset of a stimulus if our attention is already directed elsewhere. It would also appear that we can be insensitive to quite major changes in the scene if our attention is directed away from the change when it occurs, a phenomenon known as change blindness. It can be demonstrated by presenting two images on a computer screen in succession, separated by a brief interval where the screen is blank. The two images are identical with exception of one change - the deletion or addition of an object, a change in an object's size, position or colour. The images are shown repeatedly until the participant notices the difference. Often the pairs have to be shown many times before this happens, although once detected, the change can appear extremely obvious.

A similar experiment by Pringle, Irwin, Kramer and Atchley in 2001 (Hole, 2007) used driving scenes photographed from a driver's perspective with the changes. They found participants were quicker to notice the changes if they were central in the field of vision than in the periphery, and had high rather than lower sensory conspicuity.

It therefore possible that the representations of environment used by drivers may be much poorer than they realize and when changes occur in this environment, if the driver is looking elsewhere at the time, they may not notice the change when they look back to the place where the change has happened. Clearly this potentially has important implications for a driver exiting a junction when required to look in both directions prior to performing the manoeuvre. The driver's decision to pull out may be based on their memory of the traffic situation in the first direction they looked, not on the environment as it is now.

3 HUMAN ERRORS – INTENDED ACTIONS

3.1 RISK-TAKING BEHAVIOURS AND MISTAKES

Drivers incur risk if they fail to detect a hazard, underestimate the danger it poses, or overestimate their ability to deal with it. However, how we perceive risk is influenced by the fact that, while driving is risky on a statistical level, for any given trip the chance of a driver being involved in a serious incident is close to zero. Therefore from an individual driver's point of view, driving carries little risk.

The extent to which an individual will engage in risky behaviour while driving will depend on the interaction of a number of different factors. The level of risk an individual is prepared to accept is determined by: personality, for example sensation-seeking and level of aggressiveness; personal experiences, such as driver education and experiences of accidents happening to them or people they know; and environmental factors such as the presence of peers in the vehicle.

Two further factors to be considered are the level of risk actually present in the road environment, in other words the objective level of risk, and the level of risk perceived by the individual. This second factor will be dependent on the extent to which the driver correctly detects and assesses the risks and how accurately they are able to assess their ability to deal with the challenges that they present. A study by Kanellaidis and Dimitropoulos in 1994 (Dewar and Olson, 2007) compared objective and subjective ratings of risk on a street in Athens, Greece. The researchers concluded that substantial differences between perceived and actual risk, where the latter exceeds the former, may be associated with increased collision frequency. If this is indeed the case, understanding drivers subjective perception of risk, in relation to different geometric highway design elements, has a role to play in the development of safer roads.

Risky driving, in particular those aspects classified as traffic violations, will also be influenced by the extent to which the driver feels that their behaviour is likely to be detected and punished, offset against rewards gained. A driver who is running late for a meeting may balance the risk of getting caught for speeding by the police, or possibly losing control of their vehicle and having a collision, against the benefit arriving on time.

The degree by which each of these factors varies will be dependent on the particular conditions or circumstances. It is also made more complicated by the fact that most collisions occur as a result of interactions between road users.

4 ROAD DESIGN AND THE DRIVER

4.1 DRIVER-PERCEPTION RESPONSE TIME

Driver perception-response time is affected by a number of factors such as age, gender, cognitive load, fatigue and the presence of alcohol or drugs in the driver's system, but also by a hazard's conspicuity, its location relative to the vehicle's path and the extent to which it fulfils the expectation of the driver. If a hazard conforms to expectation with regards to its nature and location, response time will be minimised. However, when a driver is looking for X but encounters Y, reaction time increases, as does the probability of an error. Design that is consistent with driver expectations increases the likelihood that the driver will respond correctly and quickly to situations in the road ahead. A hazard's physical properties alone do not guarantee that it will be detected if the driver's expectations and aims cause their attention to be allocated elsewhere.

As the demands of the driving task, and associated arousal levels, increase, performance will also increase up to an optimal point, after which it will begin to deteriorate. The probability of an object being detected will therefore also be affected by the amount of information being processed, or the 'cognitive load' on the driver when it first enters the field of view. Cognitive load can arise from the allocation of visual attention, thus, the greater the amount of visual clutter near the road or in clear view of the road, the greater the demand, or load, on the driver. Cognitive load can also occur as a result of processing tasks that do not require visual attention, such as talking on a mobile phone.

4.2 SUPPORT FROM THE ENVIRONMENT

The workload imposed on the driver by the road environment will be determined by factors such as: the time available to respond to a situation; sight distance; speed; the distance between road features such as junctions and bends; and the number of such road features encountered. Large changes in workload over a short distance have been associated with higher numbers of collisions (Dewar and Olson, 2007).

Over time on a particular road, a driver will establish a set of expectancies about the road's design and surrounding environment - rural, urban, high speed, low speed, winding, generally straight, grade-separated junctions, at-grade junctions and so on. The extent by which these expectancies are violated will increase or decrease the chances of user error. Design consistency within different types of road environment limits the speed adaptions a driver is required to make: if the differences become too great, for example a sharp bend after a long straight, the risk of a collision increases. Where existing road layout or environmental constraints make the speed adaption unavoidable, the extent of the adaption must be apparent to the driver from a sufficient distance to enable them to react in a safe and controlled manner. It is also important to consider whether any features or changes in the road layout could lead to misperceptions in road users as to the actual situation. Where such situations exist, they need to be addressed in such a manner that the chances of an error are reduced as much as is reasonably practicable.

It is also necessary to minimise the speed differentials between users especially where vulnerable road users are present. However, for the reasons previously discussed in relation to vehicles parked in line with the traffic direction on high speed roads, the dangers of significant speed differentials are not limited to the urban environment.

The road design and layout for a particular type of road must therefore evoke the right expectation with regard to: road geometry; the road user's own behaviour; and the behaviour of other road users. If this is not the case, relevant objects present in the scene, or changes in the environment ahead, may be missed and the action necessary to respond appropriately and safely, delayed.

5 CONCLUSION

What we are able to perceive when driving is determined by the characteristics of our visual system, our ability to correctly determine that which requires our attention, and the fallibilities and limitations of our cognitive processes.

We are also limited by our own skills and abilities and influenced by a complex interplay of personal factors specific to ourselves at a given time. We are rarely the sole occupiers of a highway and so our behaviour is constantly impacted upon by the behaviour of others around us, and our ability to cope with an ever changing environment.

There is no model which can genuinely explain and predict driver behaviour. Driving is a highly complex activity and it is therefore difficult to understand and predict. However, this complexity means that, while the human has a role in the task, driver error will always occur.

The more we can understand how and when these errors occur, the more the highway and vehicle engineers can work in their respective fields, and with each other, to minimise the likelihood of their occurrence and to reduce the severity outcome when they cannot be prevented.

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