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Crikey! It's cognitively complex

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&

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This paper provides a refresher on the complexity of the driving task by looking at cognitive performance of drivers. The paper discusses a number of psychological theories that relate to the driving task, and gives a number of examples of crashes investigated by TRL to prompt the reader to think of the potential implications of road user distraction. The incidence of 'looked but failed to see' errors is discussed, along with efforts to improve cognitive conspicuity to address this potentially common contributory factor. Links to a number of web based examples are provided due to the highly visual nature of the accompanying presentation. We make the distinction between human performance and human behaviour, we discuss why the former is almost impossible to improve and the latter can be manipulated in many ways.

Introduction

Crashes are arguably due to a combination of the limitations of human performance, undesirable road user behaviour and circumstance.

The level of variance in each of these is often forgotten in our dissection of incidents after the event. Collison investigators tend to measure and account for accidents without much knowledge of the main cause of the crash, the driver
This paper focuses on the limits of human visual performance, and how we may affect behaviour. In the limited time we have to present we focus on driver vision as it is believed that 90% of the information we use when we drive is from our visual senses (eg Sivak, 1996).

Driver performance limitations

An easy example of limitations of driver performance is *reaction times*. Prior to reacting to a trigger, a driver needs to be able to observe, detect and perceive (or comprehend) the potential hazard. This concept is relatively easily understood and communicated.

Reaction times are used for a number of basic road safety applications such as the engineering determination of sight distances for stopping. However reaction time data is a little more complicated that you first may think and vision is not necessarily perception.

There are a large number of variables that may potentially affect an ‘average’ driver's time to react to a situation: a database search revealed no less than 7,453 studies by psychologists during the period from 1974 to 1997 that dealt with "reaction times", and this excludes studies in which reaction times were not the primary topic of interest.

In a review of driver reaction time research for Institute of Traffic Accident Investigators (Hole & Langham, 1997) we described at some length the problems with generalising scientific knowledge regarding the time it takes for a person to react under laboratory or test situations to a given situation such as a road traffic accident.

We describe at some length the various stages or processes that combine together to generate a total time to react to a situation on the highway. We provided a breakdown of the typical "accident scenario" from a reaction-time standpoint. We described that a reaction time figure is a complex series of events that psychologists still seek to understand.

In our review we described that the time it takes for a driver to react to an emergency situation will depend on many factors. Firstly, the type of response that is needed to avoid the collision. For example, if the brake lights are illuminated on the vehicle in front of you the typical response is to simply apply the brakes of your vehicle. If a child runs out in front of you on a bend there are many different responses that can be made, brake, swerve, sound the horn. Generally, the more variety of responses the greater the reaction time.

Another factor that will affect the time it takes to respond correctly to an incident is the familiarity the driver has with the type of response, associated with the situation. For example, if the traffic lights change to red in front of you there is a simple familiar response – to brake gently. Compare this to the familiarity of what to do when an emergency vehicle wishes to overtake you. There are many different responses to the emergency vehicle and typically a driver has not encountered that many emergency vehicles. From a psychological standpoint, the drivers response to an emergency vehicle has not been practiced and will consequently be slower to a practiced a familiar response.

We also highlighted the critical role of the level of expectation or familiarity of what needs to be detected. How the driver interprets what they are ‘seeing’ (or even if he perceives it at all) will be greatly affected by his expectations about what might occur, where he happens to be looking at the time, his state of vigilance, etc. We concluded that drivers are most likely to detect something which they were expecting, in the general area where they were expecting it to occur. Other researchers have used this as an explanation of why motorcyclists are not detected very quickly by drivers. This is because motorcyclists are relatively uncommon compared to cars, and motorcyclists tend to use parts of the road environments that other vehicles do not use.

We reviewed the other factors that can increase the time it may take for a driver to react to an emergency situation. These factors included the level of fatigue, sleepiness, when food was last consumed (and if it was with, or without alcohol) age, time of day, and gender.

Included that typical reaction times used by crash investigators may well be a useful starting point to understand the cause of many incidents. Critically, we highlighted the need for each case to be considered carefully, especially when the incident involves the detection of a vehicle in unusual circumstances. We speculated that reaction times to successfully detect, recognise and react appropriately may be longer than the typical 0.7 to 2.5 seconds 'think' and 'decide' time often quoted in crash investigation reports.

Two theories highlight potential contributors to differences in reaction times, and also highlight the complexity of cognitive appreciation and response by drivers to the task at hand. These theories are *change blindness* and *inattentional blindness.*

Change blindness

The presentation uses a series of static images of road environment scenes with differences considered safety critical to illustrate this phenomenon. The changes are what road users might be expected to experience during driving such as different traffic signal displays, approaching vehicles at an intersection, and changes in road markings. This is known as a Flicker Task, a process originally credited to Ronald Rensink and colleagues.

The Visual Cognition Laboratory of the University of Illinois also uses gradually change images of a scene without a flicker interruption to illustrate the theory. This process is known as the Gradual Task. For illustrations of change blindness, visit: http://viscog.beckman.uiuc.edu/djs_lab/demos.html

Inattentional blindness

With large volumes of information to process in our surrounding environment, we must constantly allocate or devote our attention to selective processes to be able to interpret the wealth of input available. Should we devote attention to particular elements either due to expectation (or lack of) and task demand, then we may become effectively blind to what else is happening in that environment.

A number of examples of inattentional blindness tasks exist including those where attention is focused on counting the movements of either a bouncing basketball or counting the movements of a number of basketballs among a moving group of persons. In each example, a person in a gorilla suit appears, actively gestures within the scene, and moves off unnoticed by a large proportion of the test audience.

Examples appear on the website listed above.

Crash case studies

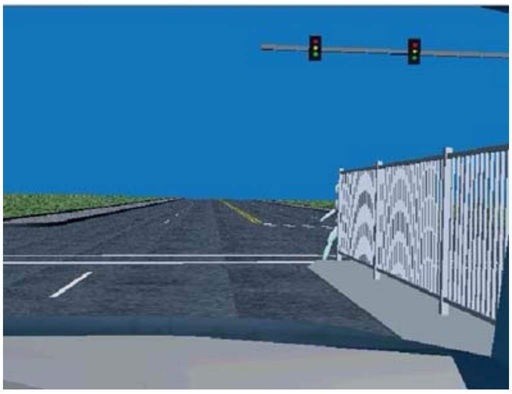
The following images are provided as an *aide memoir* of the content of the presentation. They are intended to illustrate that in real world crashes that have been investigated and reconstructed by TRL, there are a number of points that need to be remembered when considering additional driver distraction. These are:

- things happen quickly,
- things happen unexpectedly to road users,
- crashes are a combination of many factors, with inattention to various triggers in the road and traffic environment hazardous

Case 1

- CCTV footage of incident
- pedestrian steps onto road from in front of double parked vehicle

Case 2

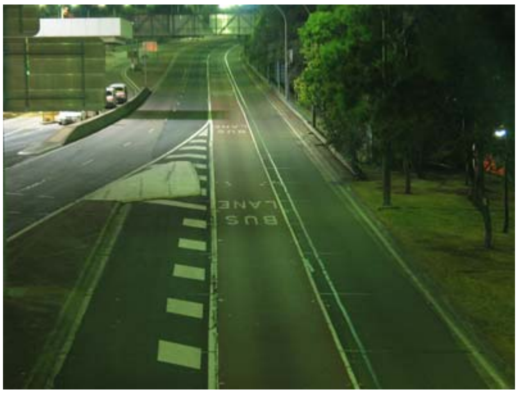


- crash reconstruction in overly simplified road environment
- pedestrian steps out from behind median fence into vehicle path

Case 3

- crash reconstruction
- truck into rear of another that strikes broken down ute in tunnel

Case 4



- crash investigation
- early morning, raining, forced change in normal travel route
- missed a number of direction signs until late, then a late lane change at the final sign resulted in the vehicle striking a median and loosing control

Case 5

- crash investigation
- traffic signals blacked out, warning sign placed by authority
- conversation among travelling friends in one vehicle, following vehuicle in front through intersection, presence of intersection unnoticed
- taxi on other approach likely to be approaching a potential customer

However, not all crashes are the result of circumstances that clearly appear hazardous with retrospective hindsight.

TRL has investigated a number of incidents where crashes seem clearly unavoidable given the road user had more than sufficient opportunity to see and react to a hazard. Examples include apparently unimpaired drivers travelling into clearly marked hazards such as emergency service and road authority vehicles with warning beacons activated and occasionally traffic management in place.

Road User Conspicuity

Vision is our most important sense when we drive. Typically those researching in the domain claim that 90% of the information we need when we drive is visual.

In very general terms the aim of the human visual perception system is to detect objects and understand where in the environment they are relative to the observer. Bright noticeable objects are often detected more readily than dull unlit objects. However, whether a target will be detected or not is not solely determined by how physically conspicuous or visible it is but whether the observer expects to see it and then knows what to do (Langham, 1999).

Human vision as much about conception as it is perception.

The ‘looked but failed to see’ (LBFS) error (Staughton and Storie, 1977) refers to set of circumstances where a driver accounts for a crash in terms of failing to detect another road user.

It has been estimated that in the range of 69-80% of all intersection crashes in Australia are caused by failures by one driver to ‘see’ another until it is too late to avert a collision (Cairney and Catchpole, 1995). The explanation of LBFS also implies that the other vehicle was there to be seen by the offending driver
In a review of driver vision and vehicle visibility, Hills (1980) describes the LBFS error as a problem of the misjudgement of speed and distance and incorrect interpretation of information by the driver. He points out that an individual vehicle accident is: “not normally due to one single cause but, rather is the result of a combination of causes.”

It may be that late detection or LBFS errors account for a large proportion of all crashes. Without the basic level of detection, no decision and response are possible. Rumar (1990), based on European data, suggests that two significant causal factors may contribute:

- a lapse of cognitive expectation, illustrated by a failure to scan for a particular class of road user or failure to look in the appropriate direction; and
- a difficulty with perceptual thresholds, illustrated by the failure to discern the relevant stimuli in lower levels of ambient illumination or where vehicles approach in the field of peripheral vision.

In interviews following ‘looked but failed to see’ crashes, the errant road user will often be adamant that they did ‘look’ for other traffic but did not ‘see’ the other road user/s and/or vehicle/s involved.

In such cases, researchers have historically investigated how conspicuous the other road user/s and/or vehicle/s involved actually were at the time of the crash. Such an approach tends to oversimplify matters and further understanding of conspicuity is necessary before any assessment or review of the liveries and/or marking systems used on maintenance and works vehicles is undertaken.

TRL has been undertaking such reviews for a range of road and emergency service authorities, in addition to large commercial fleets.

Physical Conspicuity

Conspicuity is a word that is often used without much thought of its meaning. Hills says of conspicuity:

> "It can be defined partly as the extent to which the object is above the just visible limit. It is therefore subject to the same factors as visibility, the most significant of these being the visual size of the object, its contrast with its background against which it is seen the ambient light levels and any source of glare" (Hills, 1980).

The most physically conspicuous objects possess the ability to capture the attention of the observer over and above other parts of the visual scene. Engel (1977) described physical conspicuity as the detection of a target in a brief presentation.

An object that is physically conspicuous in one environment may be easily lost in another. For example, predominantly white or lightly coloured vehicles (such as commonly used by authorities and emergency services), which provide a fair degree of contrast in dark conditions and/or against dark backgrounds, can be camouflaged by a predominantly white or lightly coloured backgrounds (such as within a white walled tunnel or brightly lit work environments).

Cognitive Conspicuity

However conspicuity is not just about how bright things are in their environment. People drive into large vehicles claiming they don't see them (e.g., Cercarelli, 1992). They even drive into highly conspicuous police cars claiming they didn't see them (Langham, Hole, Edwards & O'Neil, 2002). Not only does an object such as a maintenance or works vehicle need to be 'seen', it needs to be 'recognised' for what it is – an increased risk and potential hazard. This is a concept known as cognitive conspicuity and relates to expectation in perception and can explain why, for example, a driver can look straight at a cyclist or motorcyclist and then drive straight into them. In such a scenario, experts believe that the driver is looking for cars or larger vehicles.

Cognitive conspicuity is a dynamic parameter dependent as much upon the mental state of the observer as the physical properties of the object being observed.

Conspicuity Responses

TRL has worked with a number of fleets including road maintenance, emergency services, and the petrochemical industry.

In the case of the petrochemical industry, improving cognitive conspicuity is regarded important enough to sacrifice existing vehicle liveries and branding opportunities.

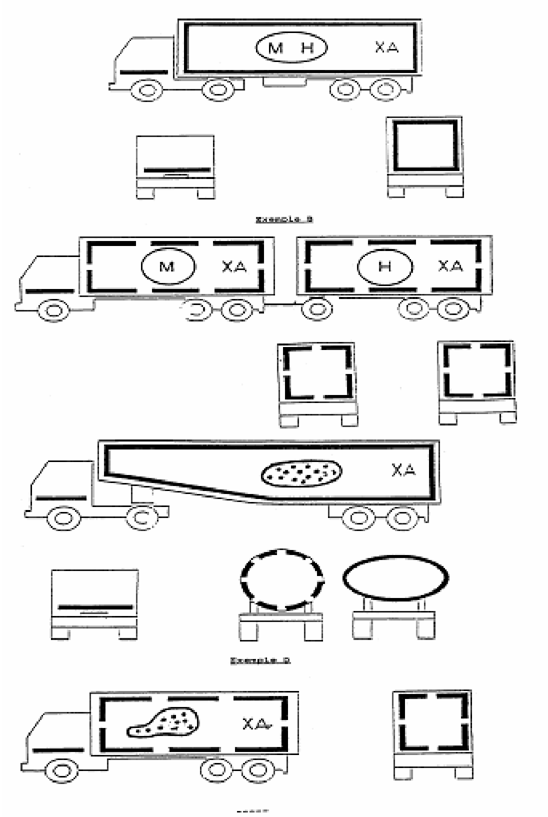


Figure 1 – An example of regulatory approach with recommended outlines or contours from UN Regulation 104.

The significance of cognitive conspicuity on road safety can be seen with moves to implement a regulatory response to improving vehicle and road user conspicuity. One such response is the United Nations Regulation 104. Figures from the regulation appear below displaying suggested outlines and contours for markings, in addition to suggested areas and management of livery and corporate advertising.

Of course, the advancement of such measures could ultimately lead to more attention being drawn away from other road users, particularly in an environment of equally competitive roadside environments, such as increased development, pedestrian or traffic activity and advertising. This could be to the detriment of some of our more vulnerable road users. The net effect is unknown.

Influence of driver distraction

Having refreshed ourselves of the limitations of driver performance (unimpaired and ignoring poor driver behaviour), and equally having seen examples of some initiatives to counter driver performance limitations, it is a good base to start considering the implications of driver distraction into a complex equation.

Typical values adopted for driver reaction times by crash reconstuctionists start from around 0.7 seconds for a comparatively alert and expectant road user (various studies) through to around 1.5 seconds (as used by the NSW Roads and Traffic Authority for urban road design) and beyond.

Research using TRL's driving simulator has shown reaction times for comparatively alert road users – given they were undergoing simulator testing – is within this range, but diminishes greatly with the introduction of distraction from mobile phone use (Burns P et al. 2002). The reduced performance (such as shown by increased reaction times) is notably worse than driver impaired by alcohol (to the 0.08 BAC level) as shown in Table 1 below.

Table 1 – TRL Simulator Reaction time findings (Burns et al., 2002)

Group	Typical Reaction Time
'Control'	0.9 to 1.1 secs
0.08 BAC	1.0.to 1.2 secs
Mobile users	1.2 to 1.6 secs

In addition to poorer reaction times, the TRL research has shown that in comparison to alcohol impaired (0.08 BAC) drivers, mobile phone users had:

- Poorer lane positioning,
- Poorer speed maintenance,
- More variable following distances, and
- Impaired judgement and gap acceptance.

This sounds alarms given our existing views and understanding of the escalated risk of collision involvement for what NSW classes as a mid-range drink driving offence, and given mobile phone user reaction times are stretched in comparison to what we have traditionally considered to be sufficiently conservative road design values. Therefore, distracted road users may not be able to cope with the basic operating environment that we are providing for them – assuming of course we have had the luxury to provide a sufficiently designed road environment and ignoring performance limitations.

In an attempt to quantify the effects of other potential distractions, TRL have since conducted further research for the Mobile Telecommunications Health Risks Research Programme of the UK Department of Health. A copy of a paper of the results of this research in attached as Appendix 1. An extension of this research is currently being prepared.

Conclusion

This paper has presented some of the background to the need for caution with the introduction of driver distractions due to the potential effects on cognitive process.
The potential significance of this extra burden is shown by illustrative examples of particular crash investigations and also by previous TRL research that suggests that 95% of crashes have human factors (or errors) as being causal or contributory.

Human factor limitations include both driver performance and driver behaviour issues.

Driver performance is limited in a number of ways. Limitations such as reaction times, can be to some extent accommodated by the system with some degree of consistency. However, other limitations, such as the theories of *change blindness* and *inattentional blindness*, contribute inconsistent limitations with more complex cognitive process being involved.

It is some of these more erratic performance areas that may realise the greatest adverse consequences of additional driver distraction.

Cognitive conspicuity is one example of the potential influence on collision incidence. Driver distraction may be outweighing measures to enhance cognitive conspicuity.

With such a complex task environment and interactions, we must be particularly cautious with the introduction of any additional cognitive loading that may increase risk.

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Staughton, G. C. and Storie, V. J. (1977), Methodology of an in-depth accident investigation, Survey Report no 672, TRRL.

United Nations (1998) Regulation No. 104: Uniform provisions concerning the approval of retro-reflective markings for heavy and long vehicles and their trailers, United Nations Economic Commission for Europe, Geneva (2000 – Amendment 1).

Forthcoming Publications

The following TRL documents will shortly be released and may be of interest to readers.

- TRL634. Mobile phone use by drivers, 2000-03 by J Broughton and J P Hill.
- TRL635. A survey of mobile phone use by drivers, April 2004 by J P Hill.

For further information, visit the publications section of www.trl.co.uk

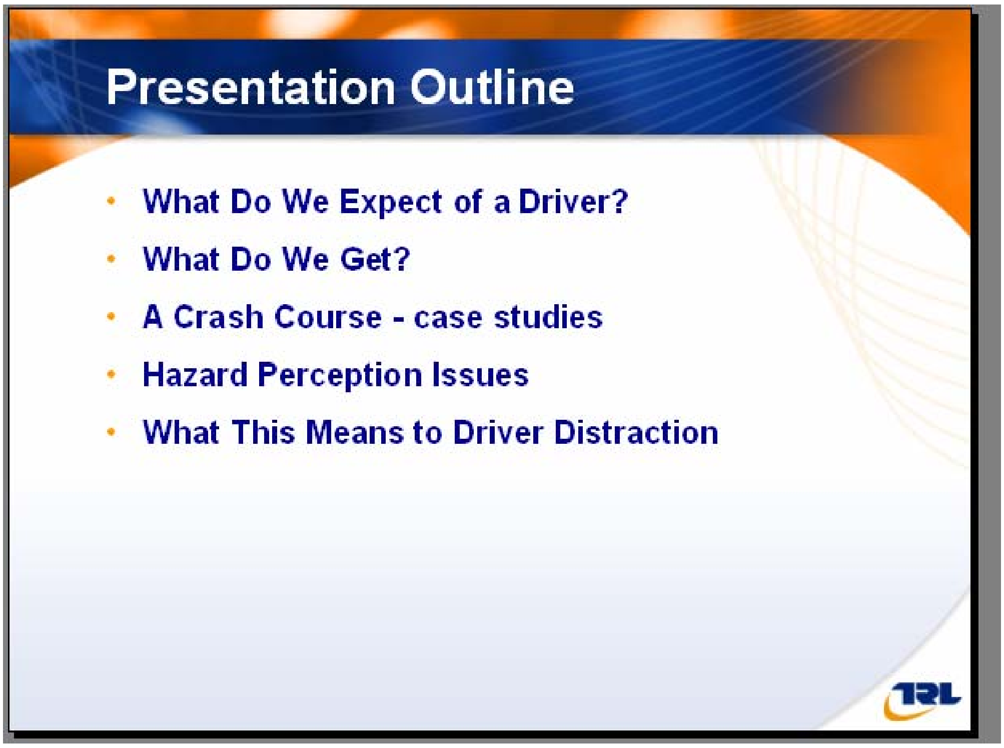
Footnote – UK *Think!* Road Safety Campaign

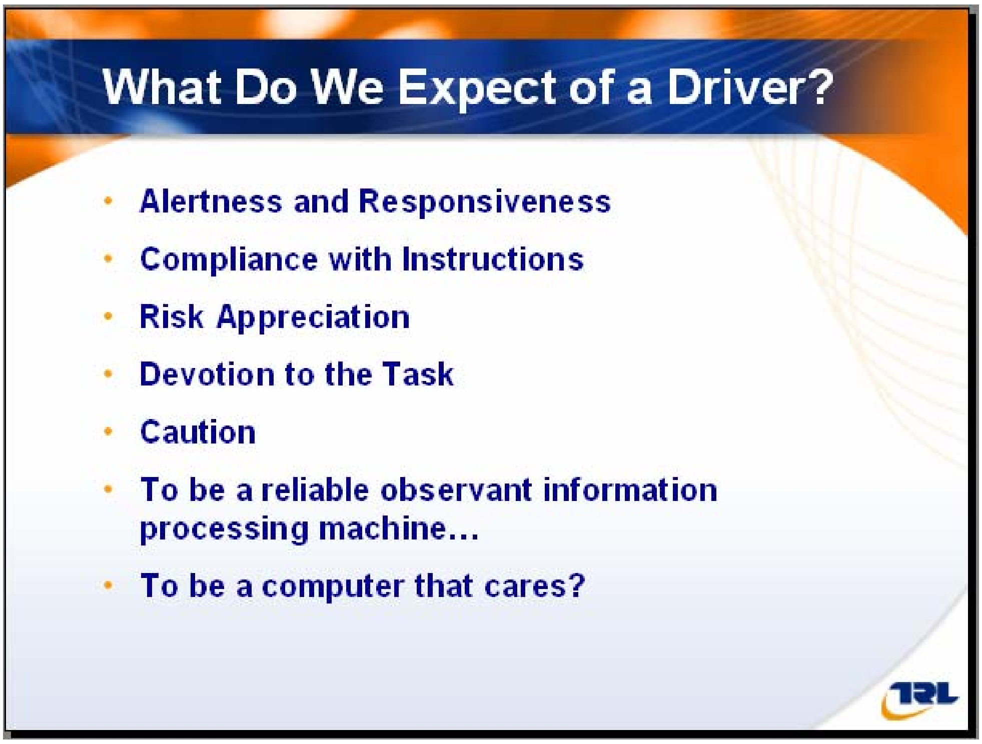
Shown during the presentation was an example of a campaign in the United Kingdom that highlights the potential difficulties associated with using a mobile phone. The advertisement uses a combination of visual information and competing voice over. The campaign is visible at :

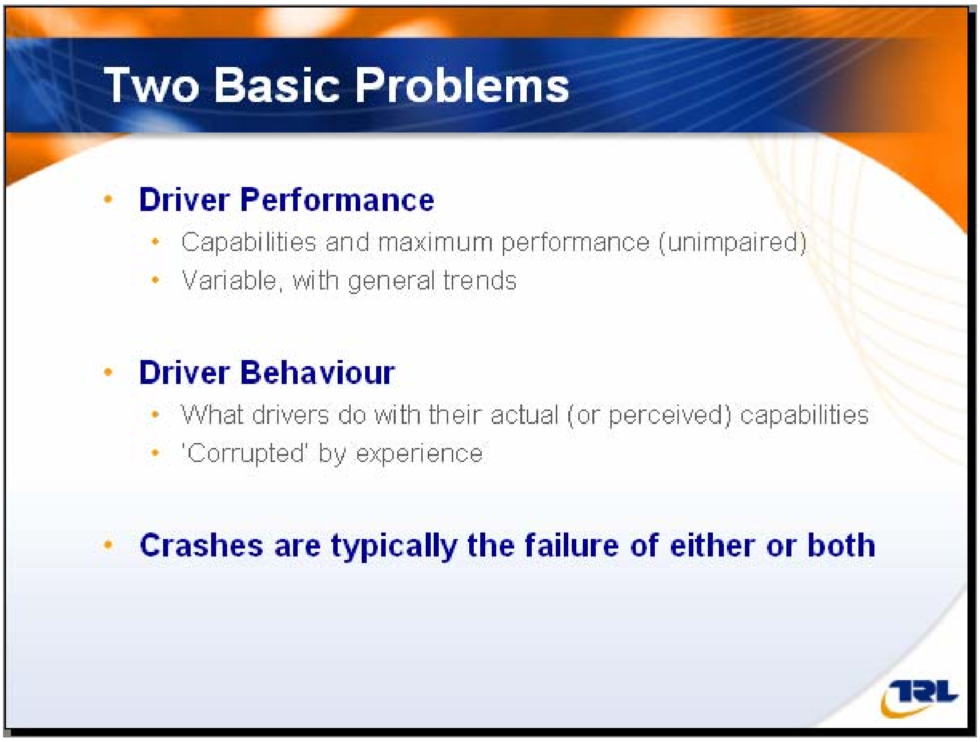
http://www.thinkroadsafety.gov.uk/

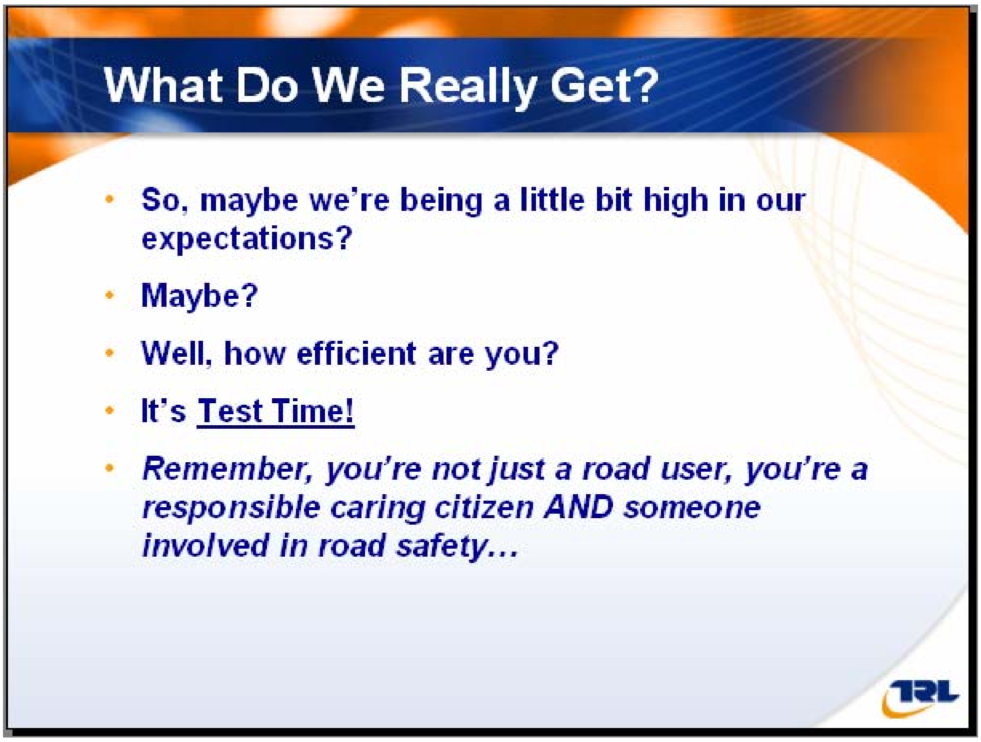
The Mobile Phone Campaign files can be found under the Road Safety Campaigns heading.

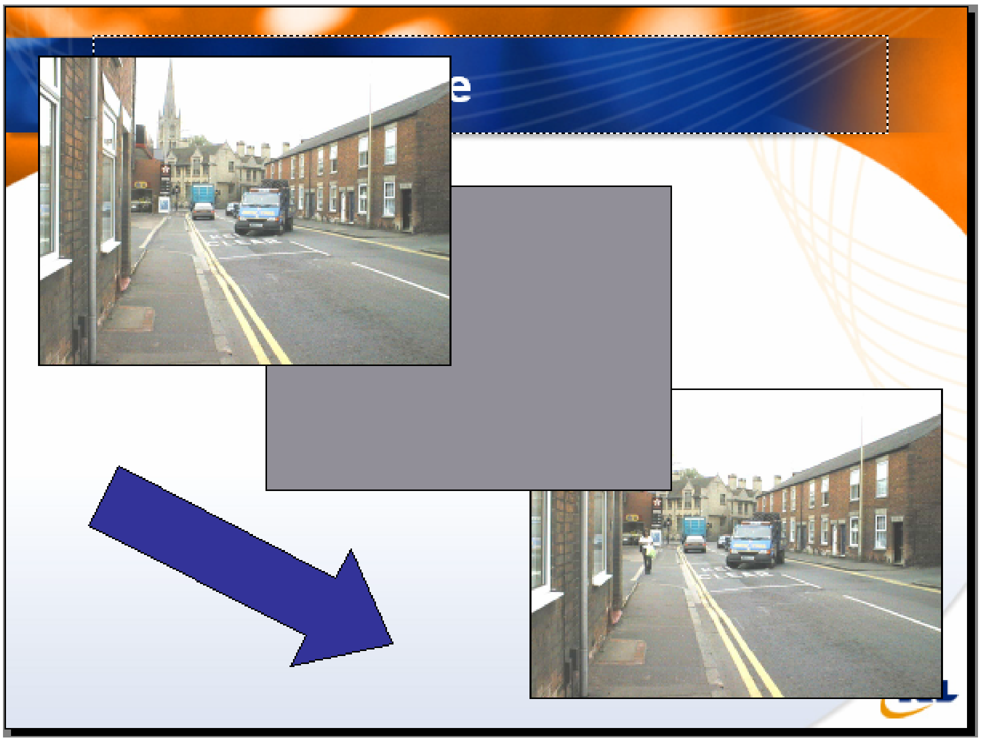
PRESENTATION SLIDES




What Do We Expect of a Driver?
Alertness and Responsiveness
Compliance with Instructions
Risk Appreciation
Devotion to the Task
Caution
To be a reliable observant information processing machine…
To be a computer that cares?
TRL


Two Basic Problems
Driver Performance
Capabilities and maximum performance (unimpaired)
Variable, with general trends
Driver Behaviour
What drivers do with their actual (or perceived) capabilities
'Corrupted' by experience
Crashes are typically the failure of either or both
TRL


What Do We Really Get?
So, maybe we're being a little bit high in our expectations?
Maybe?
Well, how efficient are you?
It's Test Time!
Remember, you're not just a road user, you're a responsible caring citizen AND someone involved in road safety…
TRL




FIVE
BELLS

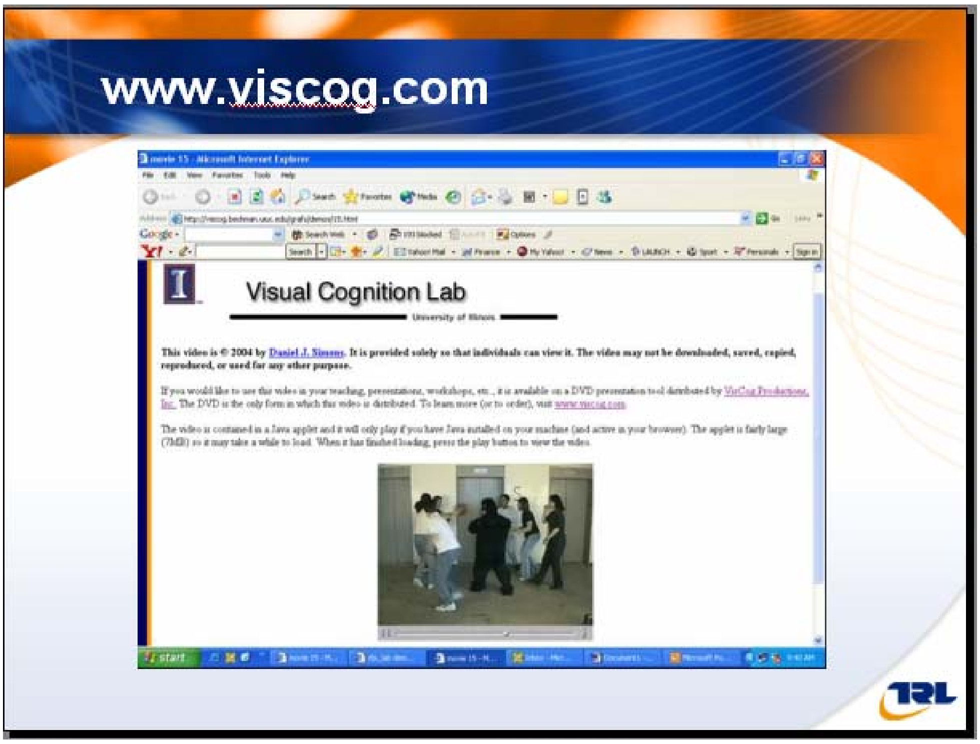
How'd You Go?

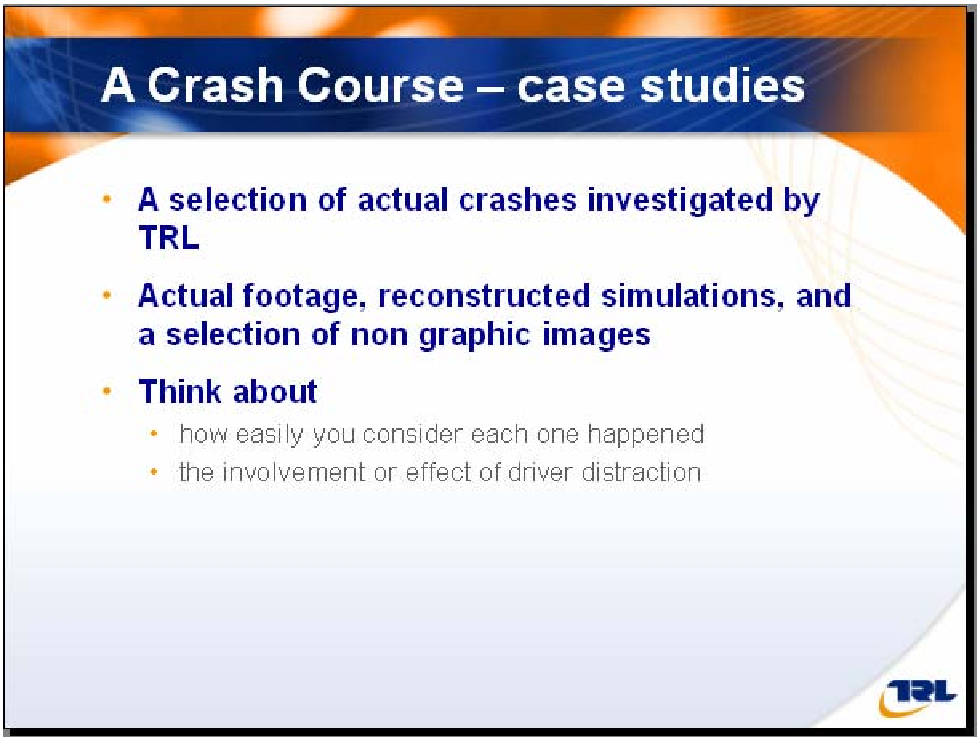
- All four images were similar to what we might expect a driver to take in at a glance and respond accordingly.
- Given that, how'd you perform?
- Every picture (pair) was different. All had safety critical changes
- Theory of *Change blindness* – 'Experts' in the domain should detect the changes, non-experts will perform poorly
- Vision is not perception

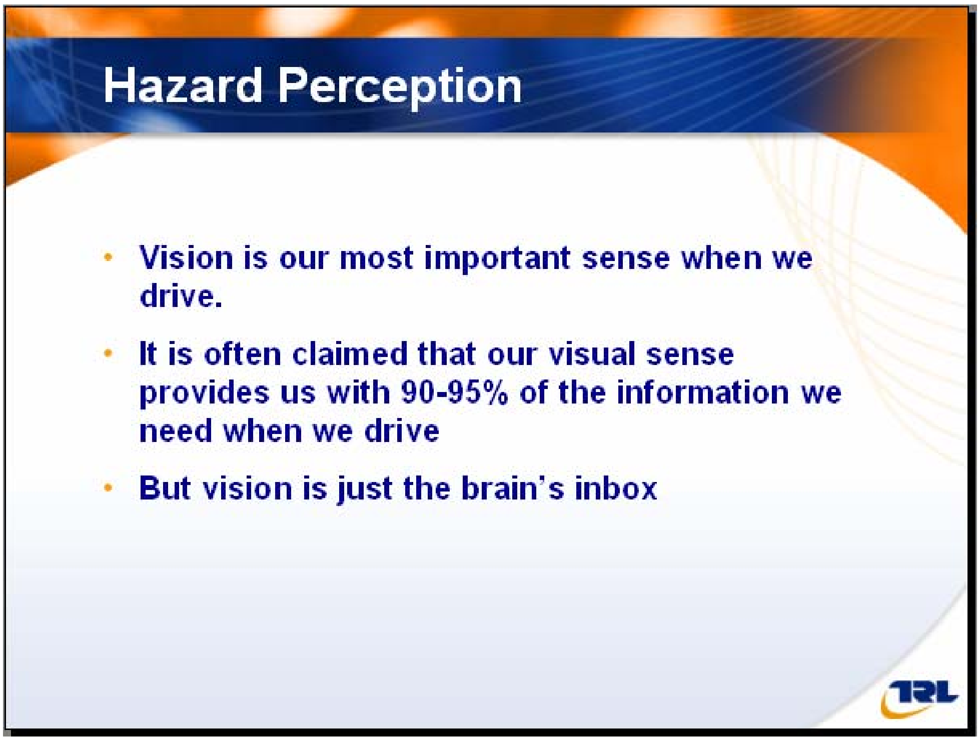
Focused and Alert?

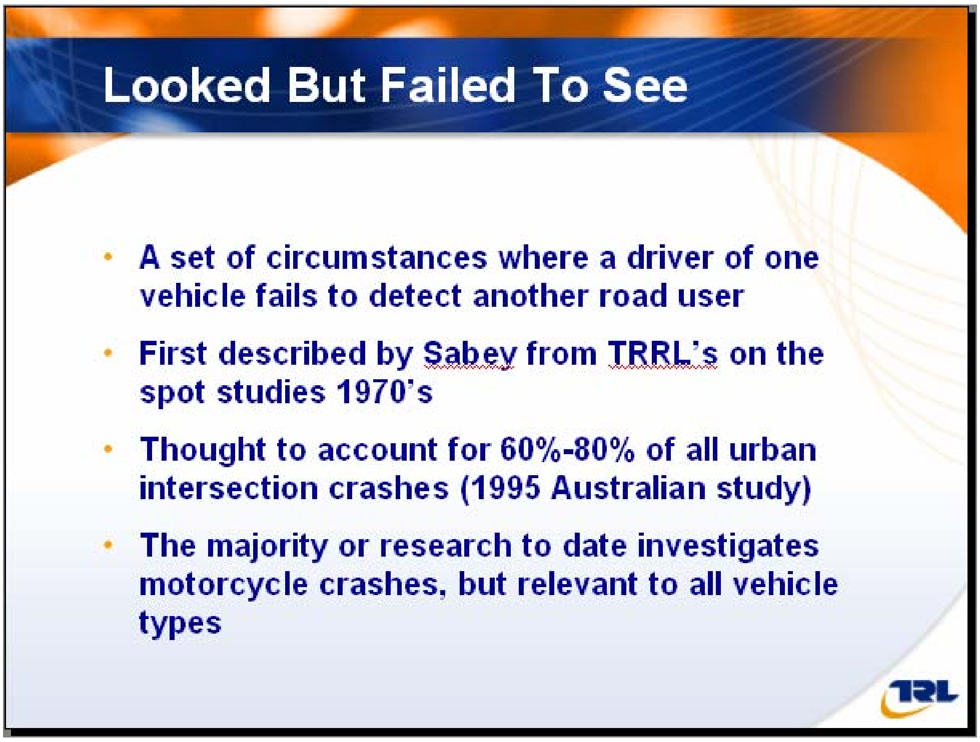
- Drivers are not always alert to the task
- Unexpected things happen
- Attention can be focused elsewhere

- Theory of *Inattentional Blindness*


www.viscog.com
Visual Cognition Lab
This video is © 2004 by Daniel J. Simons. It is provided solely so that individuals can view it. The video may not be downloaded, saved, copied, reproduced, or used for any other purpose.


A Crash Course – case studies
A selection of actual crashes investigated by TRL
Actual footage, reconstructed simulations, and a selection of non graphic images
Think about
how easily you consider each one happened
the involvement or effect of driver distraction


Hazard Perception
Vision is our most important sense when we drive.
It is often claimed that our visual sense provides us with 90-95% of the information we need when we drive
But vision is just the brain's inbox
TRL


Looked But Failed To See
A set of circumstances where a driver of one vehicle fails to detect another road user
First described by Sabey from TRRL's on the spot studies 1970's
Thought to account for 60%-80% of all urban intersection crashes (1995 Australian study)
The majority or research to date investigates motorcycle crashes, but relevant to all vehicle types
TRL

(Physical) Conspicuity

- Definition of conspicuity: detection of target in a brief presentation (Engel, 1977)
- Conspicuity measures the propensity of an object to attract an observer's attention
- Visibility measures ease of discrimination for an object with known location

Physical conspicuity

Cognitive Conspicuity

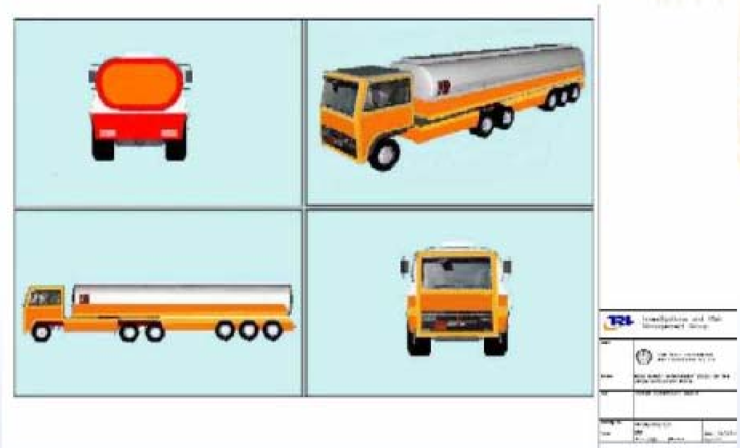
- The physical properties of an object are key determinants of conspicuity, but the expectancy levels of the observer are also important
- Conspicuity is therefore a dynamic parameter dependent on the mental state of the observer as much as the physical properties of the target (e.g. contrast, colour, luminance)

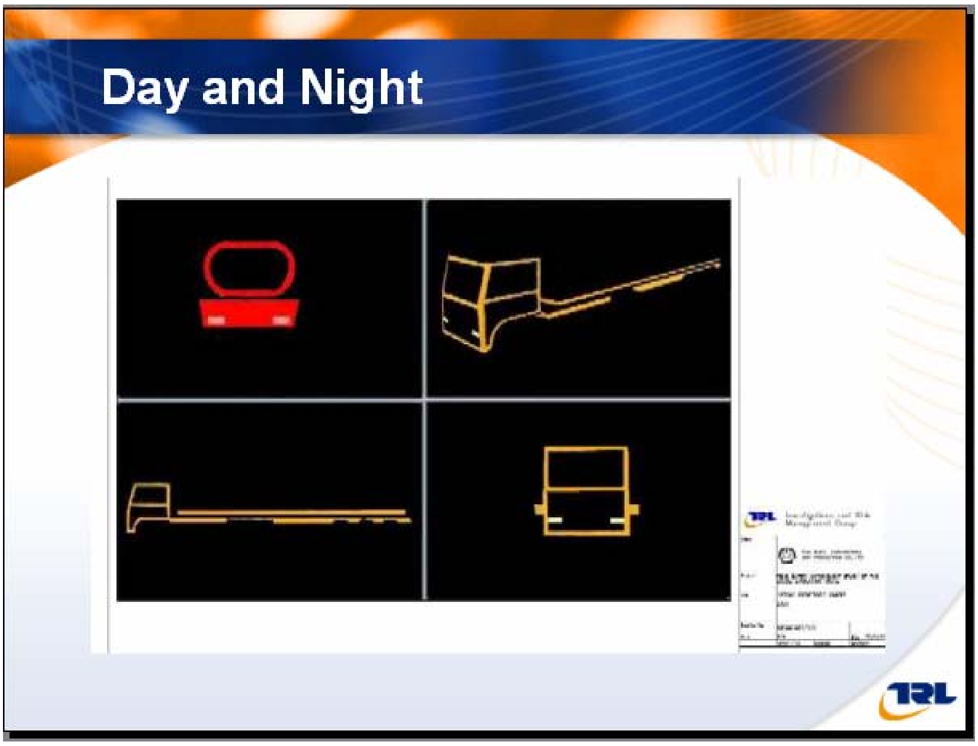
Naval camouflage

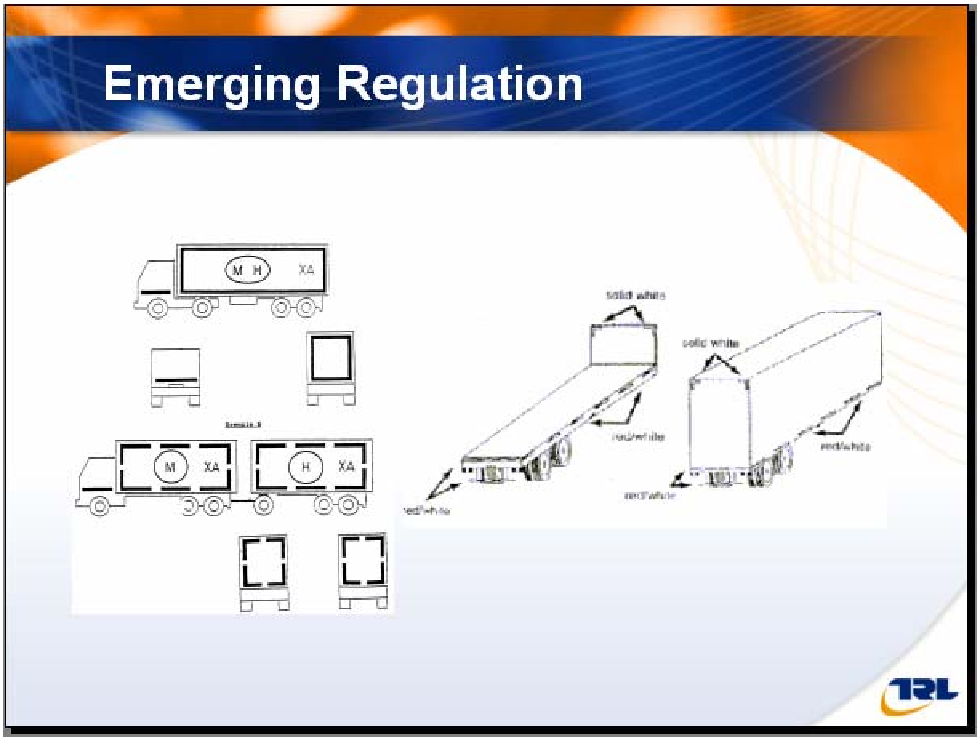
What Psychology Tells Us

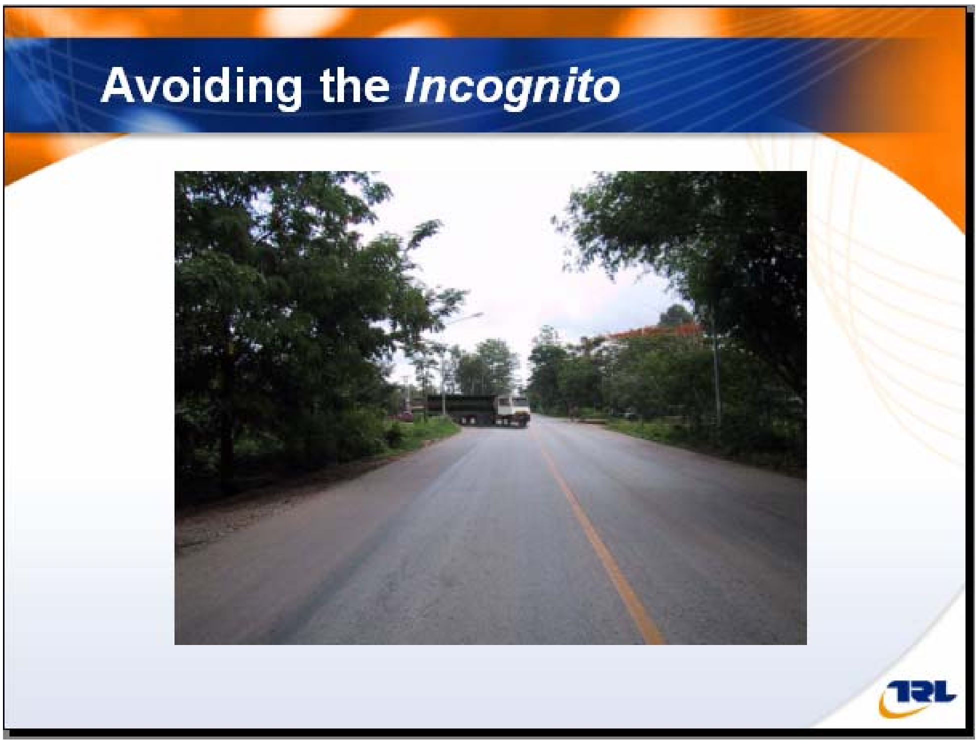
- Perception is all about recognising objects
- Perception is about the needs goals and expectations of the observer
- There are two forms of conspicuity
  - Physical
  - Cognitive
- Psychologists view is that physical conspicuity has only little to do with detection
- Road Safety view is that physical conspicuity has everything to do with detection
- The idea that perception is complete and reliable is only illusory

Improving Cognitive Conspicuity




Day and Night


Emerging Regulation
M H XA
M XA
H XA
solid white
solid white
red/white
red/white
red/white
red/white

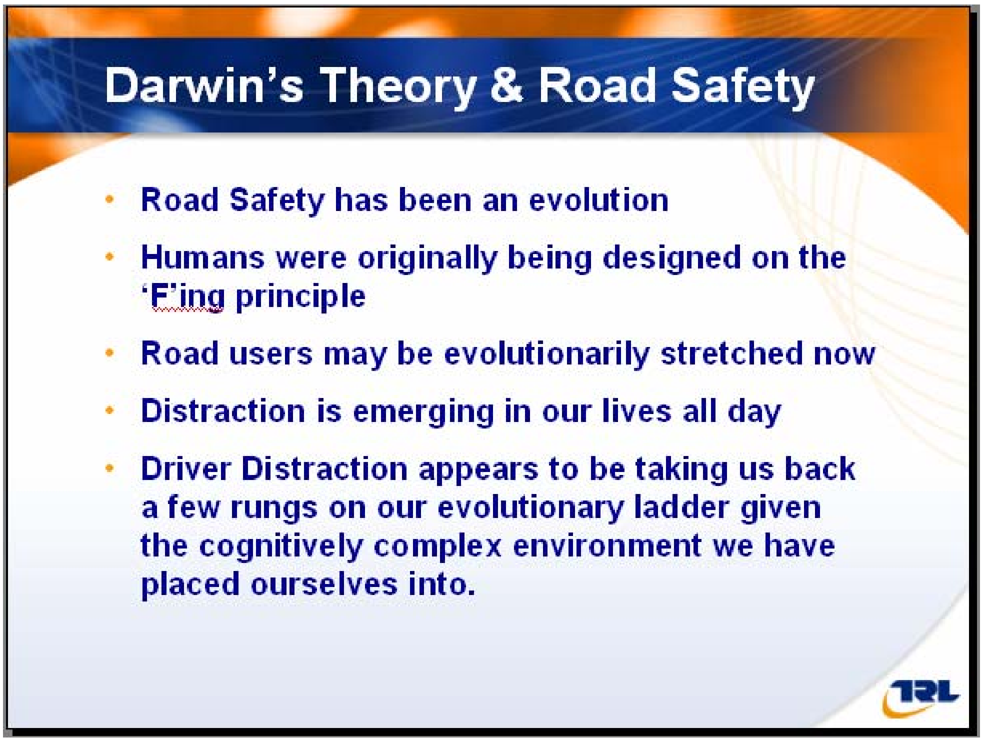

Avoiding the *Incognito*


Better…


Much better…


A Battle Against Driver Distraction?
Are we reaching cognitive overload?
Performance is already limited
Change blindness
Inattentional blindness
Cognitive recognition
Driver behaviour is 'limited'
And to the equation we add distraction?
Experience it for yourself…..

e.g. Mobile Phones
• Current research for road design adopts various times for driver's ability to detect, perceive and then finally react to hazards in the road environment
• 0.7 seconds and up – alert and expectant road user
• 1.5 seconds – RTA Road Design Guide (urban)
• TRL driving simulator research:
• 0.9 to 1.1 seconds – 'control' reaction time
• 1.0 to 1.2 seconds – alcohol impaired (BAC 0.08)
• 1.2 to 1.6 seconds – mobile phone users
TRL



Darwin's Theory & Road Safety
• Road Safety has been an evolution
• Humans were originally being designed on the 'F'ing principle
• Road users may be evolutionarily stretched now
• Distraction is emerging in our lives all day
• Driver Distraction appears to be taking us back a few rungs on our evolutionary ladder given the cognitively complex environment we have placed ourselves into.
TRL


If we don't keep on top of driver distractions, we might well need to consider our place on the evolutionary ladder when it comes to our choice of transportation.
TRL

APPENDIX 1: Burns, Parkes & Lansdown

CONVERSATIONS IN CARS: THE RELATIVE HAZARDS OF MOBILE PHONES

Peter C. Burns, Andrew M. Parkes[*] and Terry C. Lansdown[+]
Transport Canada, [*]TRL Limited, [+]Heriot-Watt University
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The present study compared the distraction from hands-free phone conversations to other common distractions in vehicles. Thirty experienced drivers aged between 21 and 64 years drove a 17 km route in the TRL driving simulator for each experimental condition. Driving performance was significantly better during the baseline drive compared with the task conditions (speaking on hands-free carphone, in-vehicle tasks, or talking with a passenger). Overall, the driving performance measures did not discriminate between the three task conditions. The main, and most important exception was found with hazard detection performance. When drivers performed a choice reaction time task to warning signs, reaction time was significantly slower for the hands-free phone condition in comparison to the in-vehicle tasks, talking with a passenger and baseline drive. Subjective mental effort was rated highest for the hands-free drive and lowest for the baseline drive. Hands-free was significantly more demanding than either the passenger conversation or in-vehicle task drives. It is concluded that hands-free phone conversations impair driving performance more than these other common distractions.

INTRODUCTION

Background

An increased risk of motor vehicle collision has been associated with mobile phone use while driving using real world collision data (e.g., California Highway Patrol, 2002). This is supported by over 30 years of experimental research showing phone conversations impair driving performance both in driving simulators and in real road trials (e.g., Brown et al., 1969; Burns et al., 2002; Parkes, et al., 1993). Despite this research, doubts still remain about the safety of phone use in cars. Phone advocates argue that phones should not be singled out by safety legislation because they are no worse than the many other distractions in vehicles (e.g., passengers and radio). This study aimed to investigate this claim.

Objectives

The objective of this study was to compare the distraction from hands-free phones to the distraction caused by conversations with passengers and in-vehicle tasks. It was hypothesised that hands-free phone conversations while driving are more distracting than talking with passengers. It was also hypothesised that driving performance would deteriorate during the phone conversation – more so than when performing conventional in-vehicle tasks.

METHOD

Subjects

Thirty experienced drivers aged between 21 and 64 (M = 40.9, SD = 12.39) participated in this study. They were all healthy and experienced mobile phones users. The sample was split evenly by gender. The sample of mobile phone users was randomly selected from the TRL volunteer database, a pool of over 1300 drivers representing a cross-section of the local driving population.

Procedure

Participants were asked to drive as they normally would and to respond to the requests of the experimenter at various times during their drive. The order of the conditions was balanced. There were four driving conditions: 1) Baseline, 2) In-vehicle, 3) Passenger and 4) Hands-free. The Baseline condition consisted of driving only without other tasks. Drivers performed in-car tasks while driving during the In-vehicle condition. These tasks consisted of adjusting the fan, fan mode and temperature on the climate system, turning on/off the CD player, adjusting the volume, changing track and searching through the tracks on the CD. The CD tracks were recordings of weather reports, traffic reports, news and various music styles taken from popular radio stations. These tasks were designed to represent tasks performed during a typical drive. The Passenger condition consisted of set conversations with the experimenter sitting next to the driver. Conversations were also had with the experimenter using a hands-free phone during the Hands-free condition.

Conversation Task. The topic for both conversation conditions consisted of monologues, repeating sentences and verbal puzzles prompted by the experimenter at set points along the route. Questions were used from the Rosenbaum Verbal Cognitive Test Battery (RVCB), which measures judgement, flexible thinking and response times (Waugh et al., 2000). The battery is composed of remembering sentence and verbal puzzle tasks with five levels of difficulty. These questions were balanced across the conditions and also included short monologues on familiar topics (e.g., forty seconds describing a recent holiday).

Subjective workload measures were taken using the Rating Scale for Mental Effort (RSME) at the end of each of the conditions (Zijlstra & Van Doorn, 1985). Upon completing the experiment, the drivers were debriefed as to the exact aims of the study, and any questions they might have about the study were answered.

Route and Traffic Scenarios. Participants drove a 17 km route that was composed of four different segments. The route started with a car following task on a motorway (3.5 km). After this, drivers were instructed to drive as they would normally on a motorway. The 3-lane motorway had a moderate amount of traffic and the speed limit was 70 mph (113 km/h), the standard speed for UK motorways. The traffic varied in speed and could overtake or be overtaken depending on how the subject drove. The motorway continued for 4.7 km. A section of curved road was used to measure the driver's ability to control the vehicle on a more demanding type of rural road (3.6 km). The curves were followed by a 5.3 km section of dual carriageway (2 lane road). During this section, drivers had to respond selectively to 24 warning signs at various points along the dual carriageway. They were instructed to flash their headlights whenever a particular target sign appeared. There were 4 different warning signs in this choice reaction time task: Elderly pedestrians, Pedestrian crossing, Cyclists and Roadwork. Each sign appeared 6 times.

Equipment

The TRL driving simulator was used to perform this study. It consists of a medium size saloon car surrounded by 3 X 4 meter projection screens giving 210 degree front vision and 60 degree rear vision, enabling the normal use of vehicle mirrors. The road images are generated by advanced Silicon Graphics computers and projected onto the screens. The car body is mounted on hydraulic rams that supply motion to simulate the heave, pitch and roll experienced in normal braking, accelerating and cornering. The provision of car engine noise, external road noise, and the sounds of passing traffic further enhance the realism of the driving experience.

A professionally fitted Nokia hands-free phone kit was used with a Nokia 3310 phone, the most common phone in the UK at the time. The phone bracket was mounted on the upper left side of the centre stack within easy reach and view from the driving position. The in-vehicle radio tasks were performed on an aftermarket Radio/ CD player (Sony CDX - CA600). The original climate controls of the Rover 400 series car were used for the climate tasks.

RESULTS

Driving Performance

There were significant differences in driving performance between the baseline condition and the three task conditions. Driving performance was significantly better during the baseline drive for standard deviation of lane position, standard deviation of following time-headway, standard deviation of speed and mean speed. There were no consistent significant differences across the Passenger, In-vehicle and Hands-free conditions for these same measures.

A one-way repeated measures ANOVA was calculated for the median reaction time ratings across the four conditions (see Figure 1). The mean reaction time data were significantly skewed so median reaction times for the six events were used. This median data was normally distributed. There was a significant main effect by condition for median reaction time [$F(2.4, 84) = 24.39$, $p < 0.001$]. There was a significant problem of sphericity with the data, so a Huynh-Feldt correction was used. Post hoc tests were run to compare the reaction times. Reaction time was significantly slowest for the hands-free phone condition in comparison to the in-vehicle tasks ($p = 0.046$, one-tailed), talking with a passenger ($p = 0.03$, one-tailed) and the baseline drives ($p < 0.001$). Reaction times in the baseline drive were also significantly faster than during the in-vehicle task ($p < 0.001$) and passenger drives ($p < 0.001$).

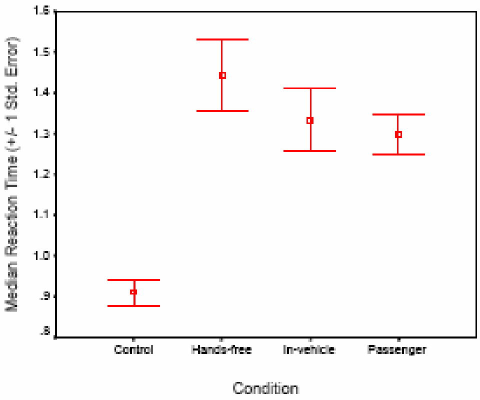
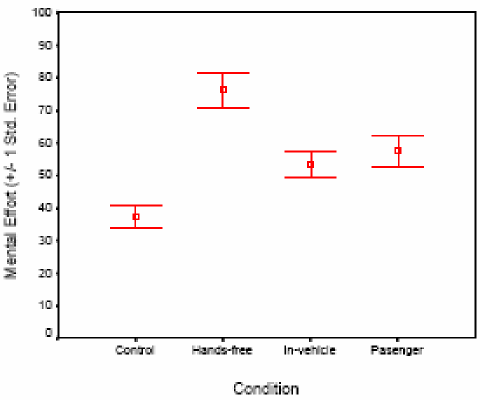


Figure 1. Median Reaction Time to Warning Signs.

The highest number of missed targets was in the hands-free drive (n = 31) followed by the in-vehicle task drive (n = 27) and passenger conversation drive (n = 22). Only one target was missed in the baseline drive. This data was significantly skewed so a nonparametric Friedman's test was used. The number of misses differed significantly across the four conditions [chi-square = 21.6, $p < 0.001$]. Post-hoc comparisons showed significant differences between the control drive and other drives. There were no significant differences among the other conditions. There were no significant differences in the number of false alarms.

Figure 2. Mean Mental Effort Ratings.



Subjective Workload

A one-way repeated measures ANOVA was calculated for RSME across the conditions (see Figure 2). There was a significant main effect by condition for mental effort [$F(3, 84) = 23.49$, $p < 0.001$]. Post hoc tests were run to compare the mean mental effort ratings by condition. Mental effort was rated highest for the hands-free drive and lowest for the baseline drive. The baseline drive required significantly less mental effort than hands-free ($p < 0.001$), passenger conversation ($p = 0.001$) or in-vehicle task drives ($p < 0.001$). Hands-free was significantly more demanding than either the passenger conversation ($p < 0.001$) or in-vehicle task drives ($p < 0.001$). There was no significant difference in the mental effort ratings between the passenger conversation and in-vehicle task drives.

DISCUSSION

The general pattern of results from the driving measures indicates that performance suffers when the driver is performing a simultaneous task. The deterioration of performance can be interpreted as an indicator of additional workload. In the baseline task the participant's attention was focused fully on driving the vehicle. In the passenger, in-vehicle and hands-free conditions a portion of their attention was focused on completing the secondary task. From these results alone there is no basis for the conclusion that hands-free phones are worse for driving. However, reaction times are more seriously affected by talking on a hands-free phone than performing other tasks.

Reaction times to selected road signs were faster in the baseline condition than the other task conditions. Reaction times in the hands free condition were slowest and there was no difference in reaction times between the passenger and in-vehicle conditions. In general, reactions are slower while driving and performing a simultaneous task, and talking on a hands-free phone has the largest effect on performance.

It can be argued that reactions govern most aspects of driving. Reaction has an even greater role to play in more complex road situations such as navigating junctions and responding to hazards. In these situations the performance deficit caused by hands-free conversations is likely to be further emphasised.

The subjective workload measures are consistent with the driving performance results. Participants rated the control condition as requiring the least mental effort and the hands-free condition as requiring the most. There was no difference in ratings for the passenger and in-vehicle conditions. The ratings for mental effort support the explanation for the driving results that using a hands-free system requires more attention than talking to a passenger or adjusting in-vehicle systems. Performance is affected to a greater extent in more difficult situations.

The relationship between the passenger and the hands-free conditions is interesting. Both allow drivers to retain full physical control of the vehicle, unlike with hand-held phones, and the conversations were equivalent. Therefore, it must be some aspect of the situation, apart from the driving and verbal task, which affects conversation performance. There are several differences between conversations with passengers and conversations over a mobile phone that might help to explain why phone conversations are more distracting. Firstly, it may be easier to hear a passenger because of the imperfect quality of the speakers on the phone/ vehicle and because of the occasionally poor reception of the mobile phone signal. The passenger can adjust their loudness and enunciation to improve communication. Alternatively, talking with a passenger could be more hazardous if there is a need for frequent eye contact and gestures. However, these same visual gestures and expressions may enhance communication and reduce the need for the driver to concentrate as much on the words.

The intimacy model of Argyle and Dean (1965) assumes that a conversation may be influenced by the medium in which it is conducted. With the participants separated visually, there is a lack of natural cues that leads to a more impersonal style of conversation. Social impact theory states that the magnitude of social influence is a function of the strength, immediacy and number of sources of influence (Latané, 1981). According to this theory the passenger would exert more social influence than the phone conversation and this would impact the demand characteristics of the task.

Several constraints were placed on the conversations in this experiment to ensure a fair comparison between the conditions. In reality, there are other factors that could make passenger conversations less distracting than phone conversations. Phone conversations may be more intense because someone has intentionally made the call so they are more purposeful or goal directed. Since the passenger and driver have a captive audience, the conversation can be less urgent and the exchange of information slower.

Another difference is that passengers may be aware of the traffic situation and can adjust their talking to the demands of the traffic, for example, they might hold a question until after the driver has negotiated a roundabout. Similarly, passengers can serve as another pair of eyes to warn the driver of potential hazards (e.g., Stewart, 2000). A combination of these reasons accounts for the finding that talking on hands-free equipment is more difficult than talking to a passenger.

Conclusions

Driving performance clearly suffers when the driver is performing a simultaneous task. Talking on a phone impairs driving more than other common distractions in vehicles.

Acknowledgments

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