Drive safely with neuroergonomics
Charles Spence on promoting safe driving through neuroscience-inspired design

The last few years have seen a rapid growth of interest in a new area of research known as ‘neuroergonomics’. How can the latest insights from psychology and cognitive neuroscience be applied to the design of multisensory warning signals, with the aim of making driving safer?

Why is driving so dangerous?
To what extent is attention (or rather a lack of it) responsible for road accidents?
Will the range of new technologies make driving safer? Or more dangerous?
Where is the best place in a car to place a warning signal?
Do multisensory cues really capture driver attention more effectively than unimodal cues?

The good news, though, is that accident rates have been in steady decline since the late 1960s, as one new safety device/intervention has followed another into the marketplace – everything from breath tests through the enforced wearing of seat belts to the ban on using hand-held mobile phones during driving. Hence, while driving is still one of the most dangerous things we do, it is, at the same time, far less dangerous than it used to be. The not-so-good news is that many of the latest in-car technologies seem designed specifically to compete for the driver’s limited pool of attentional resources:

- In the current climate, when the corridors of many an academic institution echo with talk of ‘impact’, and how to get it (or at the very least to get more of it), the much-maligned field of applied psychology is experiencing something of a revival. One area of applied research that has a longer history than most relates to the study of driving, and to the lapses of attention that lead to so many of the accidents on our roads. In fact, according to most large-scale studies, inattentiveness (including distraction and, for some, falling asleep at the wheel) is the primary cause of vehicular accidents, accounting for anywhere between 26–56 per cent of all road traffic accidents (Ashley, 2001; Ho & Spence, 2008). The figures are, quite frankly, frightening. Take, for example, the young women in my psychology lectures here at Oxford University. Statistically speaking, the most likely way for them to die while at university is at the metaphorical hands of their boyfriend, while he is at the wheel.

- The primary function of many in-car warning signals is to try and direct a driver’s attention to a potential danger. The not-so-good news is that many of the latest in-car technologies seem designed specifically to compete for the driver’s limited pool of attentional resources: everything from the mobile phone to the satnav; and from in-car web-browsing through to the ever more convoluted entertainment systems now available (see Ashley, 2001; Ho & Spence, 2008).

- Fortunately, though, the car companies are now in a position whereby the latest technologies can be used to help reduce accidents still further, by simultaneously monitoring the conditions on the road (is the road wet, is visibility low?), as well as, increasingly, the state of the driver (are they sleepy, or else driving too aggressively?). Many of today’s new cars actually have a much better idea of when a crash is likely to occur than the driver. One solution here to making driving safer would simply be for the cars of the future to take over control from the driver. This has actually been possible technically for some decades, and the state of Nevada recently legalised the first fully automated cars, or unmanned ground vehicles, manufactured by Google, for use on the public highway (Markoff, 2011). However, few drivers seem psychologically prepared for such life-and-death decisions to be taken completely out of their own hands just yet (see also Young & Stanton, 2001). Rather than taking control away from the driver, many companies have instead decided to introduce a variety of new warning signals into their cars in order to alert the driver to potential dangers. At present, though, many of these innovations only appear in high-end models, and typically only as an optional extra. The primary function of many in-car warning signals is to try and direct a distracted driver’s attention back to the road, when the car ‘thinks’ that the driver’s concentration is focussed elsewhere, and when they appear to be in danger of leaving it too late to brake. It turns out that front-to-rear-end collisions are by far the most common problem, accounting for around 25 per cent of all road traffic accidents (Spence & Ho, 2008b).

- Consequently, much of the interest in warning signal design in recent years has focused on trying to help reduce just this kind of accident.
The engineers working at the car companies have come up with a variety of innovative warning signal designs, everything from throbbing red lights on the dashboard through to sudden auditory warning beeps. Some have even considered vibrating the driver’s seat. All of these have been tried by car companies, with varying degrees of success, not to mention driver acceptance. And while the idea of vibrating the driver’s derrière might sound rather futuristic, it is worth noting that the world’s largest maker of car parts (Denso Corporation, based in Japan) is banking on the fact that all new vehicles will have tactile warning/information signals fitted as standard by the year 2020! Indeed, several cars already vibrate one or other side of the driver’s seat in order to deliver a lane departure warning signal (when, for example, the driver crosses a lane boundary too slowly; Spence & Ho, 2008c).

As the car companies increasingly start to think about making their warning signals more effective, the likelihood is that they will want to stimulate a wider range of the driver’s senses than ever before. The question that emerges, at least amongst those companies with an eye on broader developments in science and technology, is whether the emerging field of cognitive neuroscience can provide any useful insights in terms of the design of more effective (not to mention ‘intuitive’) warning signals for tomorrow’s drivers. As the executives from Toyota put it to me a few years back: ‘Can understanding the driver’s brain really facilitate the design of more effective warning signals than those that today’s most intelligent car engineers can come up with?’ Showing that the introduction of a warning signal can make driving safer is easy enough; demonstrating that neuroscience can deliver a competitive advantage over the engineer who has dedicated their life to making driving safer constitutes a far tougher challenge. Nevertheless, recent developments in brain science mean that the impact-minded cognitive neuroscientist now really does have some insights up his/her sleeve with which to help make our roads safer.

Early research
One has to go back to 1930s to find the first study in which a psychologist worked together with an engineer to try to make driving safer (Gibson & Crooks, 1938). At the time, an astonishing one in every 20 drivers was involved in an accident every 12 months. However, not much happened in terms of psychologically inspired driving research for the next few decades, until, that is, researchers at the MRC Applied Psychology Unit (as it was called back then) in Cambridge started to conduct experiments on the impact of the newly invented in-car speaker-phone (Brown et al., 1969). These devices bore little resemblance to the mobile phones of today – being about the size of a brick, and not much lighter! In the study itself, the auditory messages were relayed via a loudspeaker mounted in front of the subject, while they responded via a telephoneist’s headset. Nevertheless, Brown’s experiments were, in many ways, ahead of their time. For while many of today’s psychological studies of driving (e.g., Baddeley, 1968) – are rightly criticised in the press for their use of undergraduates (read ‘inexperienced drivers’) performing artificial driving tasks (or video games) in a laboratory setting, Brown had his participants sitting at the wheel of an Austin A40 estate car swerving down a test track between a series of variably-spaced traffic cones. Simultaneously, the drivers had to try and answer a string of logic problems presented over the speaker-phone. Risk-taking judgements and decision making were impaired by the concurrent auditory task, whereas the more automated aspects of driving, such as steering, were not. However, while the driving task was highly realistic, the auditory task was like something you might find in an undergraduate philosophy class, with drivers having to say true or false to statements of the form ‘A follows B; BA’ (based on Baddeley’s three-minute verbal reasoning test: Baddeley, 1968) – definitely not your typical mobile phone conversation. More recently, though, researchers have started to do a much better job in terms of engaging participants in driving research in more ‘naturalistic’ (albeit often scripted) conversations (Atchley & Chan, 2011; Becic et al., 2010).

Neuroscience-inspired warning signal design
Here at the Crossmodal Research Laboratory in Oxford we have been investigating the potential benefits associated with the use of spatialised warning signals to capture the attention of the distracted driver. This research, conducted both in the psychology laboratory with undergraduates and with more experienced drivers in the driving...
On-road research

To those who might want to question why we tend to conduct the study on-road rather than in a simulator, it is worth noting that it has been argued that it may be unethical (not to mention very expensive) for psychologists to conduct on-road driving research (Haigney & Westerman, 2001). Who would be responsible should the participant crash the vehicle when trying to do a difficult subtraction task, say? Fanciful though this sounds, this is precisely what happened in my first research job working on a fuel-efficient driving project for BMW back in the early 1990s. The car in which we were conducting the study was a write-off, though fortunately no one was seriously hurt. The manufacturer also kindly provided us with a brand new car to continue our on-road testing. Nevertheless, the point remains that things could have turned out very differently.

It is also interesting to note that the standards by which psychologists (and the academic peer-review process) tend to judge psychological research insights (such as innovations in multisensory warning signal design) is in terms of whether or not the result is significant as assessed by means of some standard statistical tests. By contrast, the press, rightly or wrongly, seems to think that no result regarding driving statistical tests. By contrast, the press, rightly or wrongly, seems to think that no result regarding driving

In research conducted at the national driving simulator at Crowthorne, experienced drivers reacted over 600ms faster to the sudden braking of the car in front, when given an audiotactile spatial warning signal (vs. no signal baseline) at the time that the lead car braked (see Ho et al., 2007; Ho & Spence, 2008). Putting the potential savings in terms of road safety into perspective, it has been estimated that a saving of just 500ms would result in a 60 per cent reduction in front-to-rear-end collisions (Suetomi & Kido, 1997). However, this depends on the traffic setting and density, and we must be cautious about extrapolating from an experimental study to circumstances in which repeated braking is not required.

Where, relative to one another, should the warning signals be presented? Engineers have started to investigate the benefits of multisensory cuing in driving contexts, not to mention in aviation and military applications (Ferris & Sarter, 2008; Sarter, 2000), but they rarely consider positioning. By contrast, cognitive neuroscience research shows that the so-called automatic breakdown of multisensory warning signals only occurs when the different cues are presented from the same spatial position, or at least from the same direction relative to the driver (Spence, 2010). Under such conditions, the brain appears to treat the various signals as if they are coming from the same external event. Time and time again, the engineers investigating multisensory versus unisensory signalling, get disappointing results (e.g. Fitch et al., 2007). Yet, in pretty much every case, all it takes is a quick glance at the Methods section to see that the warning stimuli were not spatially co-located. (See also Oskarsson et al., 2012.)

A second important potential neuroscience insight that is perhaps not intuitive to the engineers relates to the relative timing of multisensory signals. If one is thinking about activating specific brain structures in order to elicit a particular behavioural response from the driver, then one needs to think about stimulus timing. It has been argued that humans are designed to respond to audiovisual stimuli at a distance of 10 metres. Any further away and the sound lags the light; any closer and the visual stimulus arrives after the sound due to the physics of the situation and differences in transduction latencies (Spence & Squire, 2003). This means that inside the car, all multisensory warning signals are, in some sense, going to be presented sub-optimally (i.e. from too close to the driver), at least as far as the multisensory brain of the driver is concerned.

Hence, one active line of research for a number of car companies is to see whether they can introduce a slight temporal asynchrony between the auditory and visual or auditory and tactile signals. By so doing, these car companies hope to ensure that the various unisensory elements of the multisensory warning signal reach the appropriate parts of the driver’s brain (presumably those controlling orienting or response selection) at the right time. Once again, the idea that delaying one of the components of a multisensory signal might actually lead to faster behavioural responses is certainly not something that most engineers find intuitive (Spence & Driver, 1999). That said, we are still waiting on robust empirical data to support this particular approach to enhancing warning signals design.

A third example demonstrating the potential benefits of a neuroscience approach comes from work inspired by the single-cell neurophysiology of Michael Graziano and his colleagues at Princeton (e.g. Graziano et al., 2004). Back in the
1900s, these researchers first reported evidence supporting what appeared to be a specialised neural circuit in the brain of monkeys whose activation led to rapid defensive reactions. Subsequent neuropsychological and psychophysical research in brain-damaged and normal healthy participants, respectively, has demonstrated the reality of this representation of near-rear peripersonal space in humans as well (Occelli et al., 2011). Inspired by the neuroscientists, we recently demonstrated that auditory warning signals, especially warning signals that are designed to make the driver rapidly turn their head, are best placed just behind their head (Ho & Spence, 2009). Imagine for a moment loudspeakers embedded in the headrest. Once again, the space just behind the head is something that engineers (not to mention psychologists) rarely think about.

**Challenges on the road ahead**

Given the three examples just mentioned, I hope to have convinced you that contemporary cognitive neuroscience really can provide insights to help the open-minded engineer to design warning signals that have a realistic chance of improving road safety. However, the neuroergonomists can’t rest on their laurels just yet. Why? Well, for one thing the car of the future will likely deliver a range of different warning signals, and not just a single solitary collision avoidance signal (McKeown & Isherwood, 2007). More research is therefore needed in order to determine how the effectiveness of auditory and multisensory warning signals changes as a function of the number of different non-visual alerts that the driver potentially has to deal with.

Second, the warning signals in much of the research just mentioned were typically presented far more frequently than would be the case in the real world, where you are likely to be involved in a front-to-rear-end collision only once every 25 years or so (Ho & Spence, 2008; Spence & Ho, 2008b). While it is only natural for a scientist to try and collect as much data as possible, the danger is that a participant in a typical driving experiment may come to expect the delivery of such unusual warning signals in a way that they don’t in a real driving situation. This matters because a driver who isn’t expecting their buttocks to be vibrated is obviously more likely to exhibit a shock (or surprise) reaction than someone who is.

Researchers have, though, started to address this issue. Rob Gray and colleagues at the University of Birmingham are currently assessing the effectiveness of a variety of new non-visual ‘looming’ signals – that is, signals that start out quietly (or weakly, in the case of vibrotactile warnings) and whose intensity rapidly increases as a function of the urgency of the behavioural response that is required (Gray, 2011). The hope is that such gradual-onset warning signals may serve to alert the driver to the dangers that lie ahead, without necessarily making them jump out of their seat (with shock or surprise).

Finally, it is important to note that while many safety interventions have led to temporary drops in the incidence of accidents, only a few have led to long-term gains in road safety. Why? Well, researchers believe that many drivers may engage in ‘risk compensation’ (Wilde, 1982). The idea here is that people are happy to accept a certain level of risk while driving. Hence, if you lower the perceived (and/or actual) risk by introducing some new safety intervention or other, the danger is that a subset of drivers will simply drive more dangerously to maintain the perceived level of risk (Evans & Graham, 1991; Peltzman, 1975).

Of course, if you pursue this argument to its natural conclusion then the best safety intervention might be to put a metal spike on the steering wheel. By increasing the perceived risk in this way, or so the logic goes, the drivers should engage in safer driving. While pointed steering wheels aren’t likely to make it to the car showrooms any time soon, the point (if you’ll excuse the pun) remains that until any new safety device has been introduced into the marketplace it can be hard to predict what the long-term effects on accident rates are likely to be.

**Conclusions**

Recent developments are now opening the way for a cognitive neuroscience-inspired approach to the design of warning signals for drivers (Spiers & Maguire, 2007). Rather than ergonomics, or design based on the physical capabilities of the human operator, we are increasingly seeing a shift toward neuroergonomics, or design based on neural limitations in information processing instead. Innovations based around multisensory spatial coincidence, the possible temporal desynchronisation of multisensory warning signals, and the use of warning signals from just behind the driver’s head, all have the potential to make driving safer, especially for the growing number of older drivers (see Spence & Ho, 2008a). Hence, for those psychologists worried about the societal impact of their research in the wider community, driving research may be one place where neuroscience insights can be utilised in order to translate into tangible gains for society at large. Just don’t expect the press to give you an easy ride if you fail to consider the ecological validity of your experimental design.