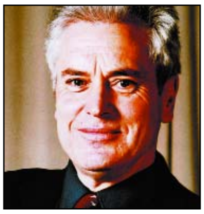
The absent mind
Attention and error



Ian H. Robertson *gave the Myers Lecture at the 2003 Annual Conference – Now pay attention.*

AT 17.24 on 8 August 1996 the London Euston to Milton Keynes train passed through a red signal near Watford Junction and ploughed into an empty goods train, killing my colleague Ruth Holland, an associate editor of the *British Medical Journal*. The driver of the train was later cleared of criminal charges for having passed the red signal; the court accepted his defence that trees and bushes had obscured it. He also told the court that he could not remember seeing two early warning signals that would have told him to expect a red light at the next signal point.

At around ten past six in the morning of Wednesday 28 February 2001 a Land Rover towing a trailer plunged from the M62 motorway near Selby, down an embankment and ended up on the southbound track of the main East Coast railway line. The driver, Gary Hart, could not move his vehicle and ran for help. Two minutes later, a GNER express travelling from Newcastle to London at 125 miles an hour ran into the Land Rover. The train was derailed. It left the track, but continued for another 400 metres before smashing into a northbound freight train, travelling at nearly 60 miles an hour. Ten people were killed, including my former colleague – the clinical psychologist Steve Baldwin. Gary Hart was convicted of causing death by dangerous driving. It transpired that he had set off from home at 5am, having had no sleep as he had been up all night talking to a woman on the phone and on the internet.

Fatigue and sleep deprivation particularly depresses the capacity for vigilant attention, with sleepiness – the failure to maintain alert responding to the external world – contributing up to 30 per cent of traffic accidents. Sustained attention is also by far the major factor in 'Signals Passed at Danger' – the most common cause of accidents on railways (Edkins & Pollock, 1997). What can psychologists contribute to the understanding – and prevention – of such accidents?

Every day in the UK and worldwide thousands of railway signals are passed at danger. Thankfully only a small number of these incidents result in tragedy – partly through good fortune and partly through the presence in some systems of backup

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safety measures. This type of error is classified as a skill-based slip that typically occurs during routine action sequences (Reason, 1992). The job of driving a train is typically routine, stopping at stations and travelling sections of track that the driver has passed many times before. Familiar surroundings and well-practised sequences of actions minimise the need for effortful attention on the part of the driver. Motorway driving has similar demands, of maintaining vigilance and alertness in the face of monotony and routine responding.

The phenomenon of vigilant attention was first studied by Mackworth and his colleagues at the MRC Applied Psychology Unit in Cambridge. These researchers were particularly inspired by the problems encountered by operators of the recently developed radar, who had to maintain attention to a small, dim and mostly unchanging screen, for rare but crucially important events – enemy or about-to-collide aircraft. The research showed that it was quite difficult to get humans to make errors on this type of detection task, but that the critical phenomenon associated with this dimension of attention was the gradual increase in missed signals over periods of up to one hour (e.g. Mackworth, 1968).

Vigilant attention is one of the three main functionally and anatomically distinct types of supramodal attentional control systems, the others being selective attention and attentional switching. Factor analysis of performance on 'real-world' tasks confirms the separability of these three factors. Robertson *et al.* (1996) used a range of tasks such as map reading, telephone directory searching and listening to a simulated broadcast of winning lottery numbers to try to sample distinct types of attention, based on hypothesised anatomically differentiated supramodal attentional systems. We confirmed the validity of these factors using confirmatory factor analysis in a children's version of the TEA – the Test of Everyday Attention for Children (TEACh) (Manly *et al*., 2001).

'The drowsy motorist and bored train driver need to internally generate sufficient arousal to avoid error'

Attending and inhibiting

Fluctuations in vigilant attention are often most readily and quickly seen in the context of routines such as driving, where the monotony of well-practised routine tends to lull the brain systems needed to maintain alertness into quiescence. The right hemisphere of the brain is critical for this internally generated 'wake up/pay attention' function – particularly the right frontal and parietal cortices (Manly, Owen *et al*., in press), working in conjunction with more primitive arousal systems in the mid-brain (Paus *et al*., 1997). People with damage to the frontal lobes following traumatic brain injury have considerable difficulty sustaining attention to such routines, particularly to those that are very simple.

This distinction can be seen clearly when you compare people with frontal lobe damage with controls on a task that requires detection of rare targets versus one that requires inhibition of response to rare targets – the latter being more closely analogous to the train driver situation. In one of my studies (Robertson, Manly *et al*., 1997) controls and traumatic brain-injured patients made statistically indistinguishable numbers of errors when they had to detect rare (11 per cent) targets – ascending or descending trios of digits (e.g. 234 or 987 in an otherwise random stream of one-per-second digits). Yet the frontally impaired patients showed twice the error rate of controls when asked to *withhold* a response, by *not* pressing a key when the number *3* appeared in a stream of randomly appearing digits (sustained attention to response task – SART). That sustained attention plays a major role in this apparently inhibitory failure can be seen when we make the inhibitory demands very low by using an entirely predictable sequence of digits – 1, 2, 3, 4, 5, 6, 7, 8, 9, 1, 2, 3… Whereas normal controls make only occasional errors on this task, brain-injured patients have considerable difficulty, and in one study made errors on 28 per cent of occasions – despite there being a totally predictable sequence leading up to the target digit. Here, by not maintaining a sufficient level of arousal and a sufficiently strong representation of the task goals ('don't respond to *3*') the patient groups default to the frequent response. This, we think, might be a reasonable model for what happens when a train driver passes through a signal at danger.

While people with TBI will not usually be train drivers, theirs is an extreme example of the malfunctioning of the brain's vigilant attention system; the phenomenon of absent-mindedness is an everyday example of such malfunctioning. Within the normal population absent-mindedness (as measured by the Cognitive Failures Questionnaire: Broadbent *et al*., 1982; e.g. walking into a room and forgetting why you came in) predicts performance on SART laboratory tasks (Manly *et al*., 1999; Robertson, Manly *et al*., 1997). We are also beginning to find marked differences in functional brain activation according to how absent-minded people typically are. A recent study, for instance, has shown that inhibition-related fMRI activation in the right inferior frontal gyrus correlated positively with the Cognitive Failures Questionnaire (Hester *et al*., 2003).

Internal versus external control of alertness

Novelty, challenge, difficulty and other external factors can increase alertness and arousal: the driver who is sleepy as he drives along the motorway may well suddenly become fully alert if it begins to snow and the car becomes more difficult to control, for instance. But in the absence of such external factors the drowsy motorist or bored train driver need to internally generate sufficient arousal to avoid error: the right frontal and parietal cortices seem to play a special role in this.

In a recent fMRI study of the SART (O'Connor *et al*., in press) we showed that, compared with a rest period, the standard SART (press to digits except 3s, which appear randomly 11 per cent of the time) showed precisely the right frontoparietal activation that we would predict as being needed for a task that placed demands on the vigilant attention system. We had previously shown, however, that performance on SART and on other tasks requiring vigilant attention could be much enhanced by presenting random alerting beeps during task performance (Manly *et al*., 2002; Manly, Heutink *et al*., in press). On the basis of these data we predicted that these exogenous stimuli activated vigilant attention, hence reducing the demands on the endogenous components of that system that we argue are based in the right hemisphere frontoparietal system.

What we in fact found was that presenting alerting tones during SART did eliminate the right-frontal activation, but did not eliminate the right-parietal activation. In other words, it seems as if the parietal component of the right hemisphere vigilant attention system may be a common pathway for both endogenous and exogenous routes, while the right-frontal element may be particularly linked to internally generated activation.

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Links between attention and arousal

Arousal has been defined as 'some level of non-specific neuronal excitability deriving from the structures formerly known as the reticular formation but now generally referred to as specific chemically defined or thalamic systems that innervate the forebrain' (Robbins & Everitt, 1995). In 1908 Robert Yerkes and John Dodson studied the effects of different degrees of arousal in mice (by varying degree of shock) on their ability to learn discriminations between the luminance of two compartments (Yerkes & Dodson, 1908). They found that where lightness levels were easily discriminated, the mice performed better at high levels of arousal – difficult light discriminations were best learned at low levels of arousal.

On the basis of these experiments they formulated the Yerkes–Dodson law. This law proposed that any task will have an optimal level of arousal below and beyond which performance will decline; this optimal level is lower in challenging tasks than in routine tasks. Similarly, Donald Broadbent showed that stress can improve performance on routine, non-demanding tasks, but the same levels of stress can impair performance on more complex and demanding tasks (Broadbent, 1971). These classic psychological studies – suggesting an interaction between arousal levels, optimal performance, and degree of challenge in a task – mesh well with the notion of exogenous modulation of arousal as previously discussed. It also suggests, however, that the relationship between the system for vigilant attention and arousal may not be a simple one of mutual facilitation, and a number of other more recent studies support such a view.

'children with ADHD have *specific* problems with vigilant attention'

Attention deficit hyperactivity disorder

ADHD is a complex condition with a number of different subtypes, and a range of associated cognitive and motivational impairments (Castellanos & Tannock, 2002). What is interesting about this disorder in the context of the current article is the fact that the 'inattentive' subtype of the disorder includes a profile of impaired sustained attention, absent-mindedness, distractibility and action slips that are extremely close to the pattern of adult behaviour I have described as being linked to a deficient vigilant attention system. In fact, children with ADHD have *specific* problems with vigilant attention – they show normal performance on selective attention tests, for instance (Manly *et al*., 2001), such as finding symbols on a cluttered map.

Bearing in mind this similarity in behaviour patterns, and without wishing to ignore the abnormalities in other brain regions such as the caudate nucleus and the vermis of the cerebellum that have been identified in ADHD, it is of considerable interest that there are also abnormalities in the right-frontal lobe – particularly in the underlying white matter (Castellanos *et al*., 1996) – in ADHD.

To summarise, aspects of the ADHD syndrome may constitute an important manifestation of deficits of the vigilant attention system. Progress that has been made towards rehabilitation of deficits in this system may potentially be applicable to ADHD. We turn to this final question now.

Attentional rehabilitation

The ability to sustain vigilant attention seems to be an important factor in determining recovery of motor and other function following stroke (Ben-Yishay *et al*., 1968; Blanc-Garin, 1994). For example, the ability to sustain attention to a tone-counting task at two months post-stroke predicted not only everyday life function two years later, but also the functional dexterity of the left hand in a pegboard task (Robertson, Ridgeway *et al*., 1997).

These findings are strongly compatible with the evidence of experience-dependent plasticity: the reshaping of the brain following injury depends on the input. It has been shown that activity-dependent reorganisation in sensory and motor maps requires active attention to the relevant stimuli: passive stimulation of the relevant circuits while attention is deployed to some second task does not result in plastic reorganisation of the stimulated circuits (Recanzone *et al*., 1993).

Impairment in sustained attention may also be a key factor in the development of the disabling condition unilateral spatial neglect, a lack of awareness in one half of the visual field – a relatively common consequence of right-hemisphere stroke (Husain & Rorden, 2003; Robertson, 2001). Apart from the disabling consequences of impaired vigilant attention itself, it is likely that impairments in this system have more wide-ranging consequences for recovery from brain damage and the learning that underpins rehabilitation effects (Robertson & Murre, 1999).

It is possible to enhance vigilant attention both in the short term through exogenous means (Manly *et al*., 2002; Manly. Heutink *et al*., in press) and over longer periods by training patients to implement metacognitive, verbally regulated strategies (Robertson *et al*., 1995), whereby they learn to talk themselves into more alert attentive states by linking short catchphrases with externally produced arousal. We have further shown that short-term exogenous activation of the vigilant attention and arousal systems can temporarily alleviate neglect-induced spatial bias in individuals with right-hemisphere damage (Robertson *et al*., 1998). Specifically, these individuals show a bias of attention to the right side and are much slower to notice visual events on the left. When an alerting beep was heard just before such visual events, this bias was temporarily reduced, even though the tone gave no information about space or direction. Similar methods have now been incorporated as an element in a more comprehensive and successful system of rehabilitation for executive problems following frontal-lobe damage (Levine *et al*., 2000).

From turgid academic prose to bipolar disorder

In studying the sustained attention system of the human brain we can follow a thread from millisecond activations in specific regions of the brain through to complex behaviours in everyday life. We also see a system whose functioning is of great importance in a range of clinical conditions, ranging from ADHD to bipolar disorder (Clarke *et al*., 2002), where specific difficulties in sustaining attention have been observed during the euthymic phase. This raises the possibility that sustained attention impairment may be a neuropsychological vulnerability marker for bipolar disorder, as sustained attention deficits were also apparent in individuals near illness onset.

Not only are we now able to understand this system better, but we have also devised techniques for improving its efficiency. If, while reading this article, you have noticed yourself having to re-read parts of it because you have been thinking of something else, blame it not only on the turgid academic prose, but also on the small inefficiencies of your right-hemisphere vigilant attention system.

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