VALIDATION OF THE STROKE DRIVERS SCREENING ASSESSMENT FOR PATIENTS WITH AN ACQUIRED NEUROLOGICAL DISABILITY

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ABSTRACT

The Stroke Drivers Screening Assessment (SDSA) is a collection of three cognitive tests found predictive of driving in stroke patients. Whilst two of the tests (Square Matrices and Road Sign Recognition) were good predictors of on-road performance, it was not known which cognitive abilities they assessed. Furthermore, it remained unknown whether the SDSA could predict fitness to drive for people with other acquired neurological disabilities.

The on-road test, considered the 'gold standard' of driving ability, was the criterion against which SDSA performance was compared. Since the SDSA's validity depends on the reliability of the driving instructor's decision, it seemed important to check that this was consistent with instructors elsewhere.

Therefore this study had three aims: -

i) To examine the content and concurrent validity of the SDSA sub tests.

ii) To determine whether the SDSA, either alone or in conjunction with other cognitive tests, could predict fitness to drive for patients with acquired neurological disabilities other than stroke.

iii) To check the inter-rater reliability of the gold standard of driving ability (used in studies to validate the SDSA).

STUDY 1

Stroke patients were assessed on the SDSA and validated tests of memory, attention, executive function and perception. Correlation coefficients were calculated to explore the relationships between the SDSA and additional cognitive tests.

Results showed that the SDSA primarily measures executive functions and attention, suggesting that attention and executive functions are important determinants of fitness to drive following stroke.

STUDY 2

Patients with acquired neurological disabilities were assessed on the SDSA and other cognitive tests and their 'fitness to drive' tested on the public road. Correspondence between the SDSA prediction and driving outcome was examined. The results showed that the SDSA alone was not a good predictor of 'on road' performance for patients with acquired neurological disabilities. It was better at predicting safe drivers. Diagnostic group differences suggest it may be more predictive for some patients than others and that different cognitive skills are important for different diagnostic groups of drivers.

STUDY 3

The independent ratings of two visiting instructors were compared to ratings made by the instructor used in earlier studies (VR) whilst road testing eight neurologically impaired patients. Driving errors were rated over 25 road manoeuvres and a global impression of patients' 'fitness to drive' made.
No principal differences in error ratings were found between the instructors but slight global rating differences were found between one visiting instructor and VR. The results suggest the decision made by VR is reliable and that the 'gold standard' of driving ability used in the SDSA validation study may be valid. However, a much larger study is necessary to confirm these findings.

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CHAPTER 1
INTRODUCTION

1.1 Driving

This literature review is based on a search of CD ROM's accessible through the University of Nottingham Library's networked resources. Those searched were Bath Information and Data Services (BIDS) Embase 1950-November 1999, Bids ISI 1989-November 1999, Medline 1966-November 1999, Science Direct 1994-June 2000, Psychlit 1994-March 2000, Cinhal 1960-November 1999 and Web of Science, Science Citation Index, 1981-June 2000.

Search terms were driving and related terms such as driving ability, driving evaluation, driving assessment and accident risk combined with the diagnostic labels, traumatic brain injury, head injury, brain damage, Parkinson's disease, disabled, stroke, cerebro-vascular accident, multiple sclerosis, elderly, Alzheimer's disease and dementia. The terms cognitive abilities and cognitive assessment were also combined with the driving terms. Other strategies included checking current publications for additional studies.

In the highly motorised society in which we live, the ability to drive a car is an integral part of independence for most adults. Driving is regarded as an activity of daily life and one that should be preserved wherever possible (Drachman, 1988; Odenheimer, 1993). The ability to drive increases mobility and has many practical advantages such as greater opportunity for socialisation and better employment prospects (Barnes and Hoyle, 1995). It also impacts on other activities of daily life such as shopping and leisure opportunities (Mollenkopf et al., 1997; Monga et al., 1997), so enabling people to fulfil roles in society, to the extent that someone who cannot drive or use other means of transport may be considered to be handicapped

(Barnes and Hoyle, 1995). Yet it is one of the few daily life activities where the driver's life and those of other road users and pedestrians are taken into the driver's hands each time he sits behind the wheel.

At some point in the recovery of people who have suffered a stroke or a severe Traumatic Brain Injury (TBI), the question will arise about fitness to resume driving. For those suffering from progressive deteriorating neurological conditions such as Parkinson's disease (PD) multiple sclerosis (MS) or dementia, the question concerns whether they are fit to continue. The very nature of these disabilities can lead to difficulty using other transport systems and patients may look to car driving as the solution to their mobility problems (Hoyle, 1993). Whilst people with severe physical disabilities are enabled to drive using adaptive technology, many people with neurological disabilities also have cognitive impairments and it is these that are often overlooked in routine driving assessment procedures and which cannot be overcome.

The combined incidence and prevalence of neurological disabilities in the UK suggests there may be as many as 1,170,500 neurologically impaired people eligible to drive. The question of whether they are 'fit to drive' is frequently asked. Attempts to answer it objectively and accurately are therefore timely and important. It is unclear how many people with neurological disabilities the DVLA advises each year on their fitness to drive a car or how many licences are refused or revoked since the current systems of record keeping mean this information is not readily accessible (DVLA, personal communication 2000). However, only a small proportion of neurologically impaired drivers (3,809 in the year 1998-1999) are seen and assessed by specialist driving assessment centres where facilities for in car testing exist (Cornwell et al., 1999). Although cognitive impairments are important features of these conditions, even in specialist centres, cognitive assessments and on road testing are not always used in decisions concerning fitness to drive (Frye, 1995).

1.1.1 The question of 'fitness to drive' in rehabilitation

In the past medical conditions were used to judge fitness to drive. However, when viewed collectively, people with medical conditions are not considered a high-risk group for accidents causing injury to other road users (Taylor, 1995). Statistical evidence suggests risks are minor (1:1000) (Grattan and Jeffcoate, 1968). Although widely quoted, this research is dated and focuses only on accidents causing serious injury to other road users. It fails to adjust statistically for the number of miles driven. In the case of older drivers, studies making this adjustment infer a substantially greater risk (Evans, 1988; 1991).

1.1.1.1 Effects of age on accident risk

In the normal elderly driver crash risk increases with age (Graca, 1986, Lucas-Blaustein et al., 1988) and per mile driven (Evans, 1988) but age alone is a poor predictor of driving skill. Crashes involving elderly people are likely to have multiple causes but occur most often among those with perceptual and cognitive difficulties (Odenheimer, 1993). Older drivers tend to crash in complicated driving situations that require focussed attention and accurate judgement about speed and distance, such as merging with major traffic streams and turning left (right in the UK) (Hunt, 1994). It is possible that studies of crash risk, accounting for the dramatic rise in people aged over 70 also include a substantial proportion of drivers with dementia (Johansson et al., 1997; Odenheimer et al., 1993).

It is not known whether people with brain damage pose a greater risk to the safety of other road users than do other disabled drivers, such as those with heart disease or diabetes. Given that many who suffer from conditions like Parkinson's disease and cerebrovascular disease also fall into the older age group, it is reasonable to assume that they have a potentially greater risk of accidents. For those with other acquired neurological disabilities such as head injury or multiple sclerosis (more prevalent in younger people) the actual risk remains unknown. However, the nature of these disabilities (affecting cognitive, visuospatial, physical and behavioural domains) and the complex nature of the driving task (requiring perceptual, cognitive and motor abilities) make it reasonable to assume that the skills required for safe driving may be compromised. This assumption is supported by large sample studies examining accident causation amongst the general population, which suggest efficient visuo-perceptual and attentional skills are important for safe driving (Staughton and Storie, 1970, Treat et al, 1977, Treat, 1980, Sabey and Taylor, 1980).

1.1.2 The risk of crashes

It is not known exactly what risk is posed by brain damaged drivers in the UK. There are many problems inherent in obtaining information on actual accident rates. Firstly, people are unwilling to divulge information because they fear it may lead to revocation of their driving licence or adversely affect insurance premiums. Many are under pressure to continue driving, often from the spouse (Rabbitt et al., 1996), especially where the car is the sole means of transport or where mobility is compromised and access to other forms of transport limited.

Other problems arise from the methods used to obtain information. Surveys tend to have poor response rates and response bias (only good drivers with nothing to lose, reply). They also rely on recall of events and self-report of accidents or incidents among patients who typically suffer from memory impairments. Attempts to ascertain information from insurance companies are futile as they are bound by confidentiality and fears of market rivalry. However, they may be willing to contest the assumption that brain damaged drivers pose no increased risk (M.J. Fish and Co., Personal Communication, 1995).

Attempts to follow up patients assessed by specialist driving assessment centres are also problematic. Not only is response bias an issue (Simms and O'Toole, 1994) but those who attend for assessment may be a selected group. They arguably consist of patients who report for assessment as a matter of duty and of the very worst drivers who are sent by their GP's, families and the Driver and Vehicle Licensing Agency (DVLA), to persuade them to stop driving. Those who have lost insight into their abilities or who feel pressure bound to continue driving may go undetected and it is these people who may present an increased risk and in whom interest lies.

Studies of driving in brain damaged subjects provide conflicting evidence about the risks posed. In a review of the literature, Van Zomeren and colleagues (1987) identified that, of the patients with acquired brain damage in the Netherlands, only half continue or resume driving and statistics show no increase in traffic violations, suggesting they are not a high risk group. Katz et al., (1990), followed up 22 brain damaged patients a mean of 2.7 years after evaluation by a physician, neuropsychologist and driving specialist. All had been judged by them to be safe drivers. When compared to a friends and spouses control group on driving status, offences and accidents, no significant differences were found between the groups on any measure. Those who had and had not experienced difficulties on the road were compared on initial neuropsychological screening, again no significant differences were found. The authors concluded that selected brain damaged patients are as safe as their matched controls.

Kumar et al (1991) followed up 16 stroke patients six months and two years after driving evaluation. After two years only one patient had been involved in an accident. Hazelkorn et al., (1998) in a cohort study, compared patients with Cerebro Vascular Accident (CVA), Traumatic Brain Injury (TBI), extremity fractures and appendicitis with age and sex matched controls. Using hospital records to identify patients and cross checking those identified with the licensing bureau (DOL), they looked at the number of crashes and moving violations cited by the DOL in the 12 months before and after hospitalisation. Risk estimates (for crashes and moving violations) were calculated for the four cohorts and the controls. These were based on the assumption that a single crash or citation may not be the patient's fault but two or more were likely to be so. Personal characteristics such as risk taking behaviour, which may have affected the risk estimates, were also taken into account. They found that people with CVA were found to be at decreased risk of crash or citation after a stroke. Patients with TBI had a modestly increased risk of receiving a citation but not of receiving two or more in a 12 month period. Unfortunately no adjustment was made for the number of miles driven.

In a study of drivers with Parkinson's disease (PD), Dubinsky et al., (1991) found they had no more lifetime accidents and committed fewer driving offences than other drivers but those with more severe PD had more accidents per mile driven. Cognitively impaired drivers had more accidents than those without cognitive impairment, irrespective of disease severity. In a study of accident statistics among drivers with multiple sclerosis (MS), Knecht (1977) found that those with MS caused significantly more offences than controls. In an American study of 35 head injured patients followed up two years after injury Pidikiti and Novack (1991) found 21 had resumed driving without any form of evaluation, two had subsequently been involved in crashes, one resulting in a fatality.

Those with mild dementia have more accidents than their age-matched controls (Adler et al., 1996) and an increased risk of fatal road accidents. Johansson and colleagues (1997) examined the brains of 98 drivers aged 65 and over, killed in road traffic accidents in Sweden and Finland. They found that 47-53% of drivers killed may have had incipient AD. In a survey of 522 consecutive patients seen in a dementia clinic (Gilley et. al., 1991), approximately one third were reported to have driving difficulties and two thirds had crashed in the six months before the study. No relationship was found between Mini Mental State Examination Scores (MMSE) and driving problems but there was a significant relationship between sedative use and crash risk in demented drivers.

In Great Britain, cross checking of hospital records and those kept by the DVLA is made virtually impossible by the disparate ways computerised medical records are held across health regions or in different parts of the country (Barnes et al., 1998). Some hospitals record little more than names, addresses and admission and discharge dates. Unless specific departmental records are held, it may be impossible to identify patients according to their medical diagnosis. Without these systems in place, there is no reliable method of cross-checking patient records with those held by the DVLA. Even if records were reliably maintained, many people with acquired neurological disabilities are not admitted to hospital, so attempts to determine risk in this way would be patchy and inconclusive. Identifying (via the DVLA) which patients with acquired neurological disability have resumed driving is also likely to be problematic because existing methods of self-declaration are thought to be unreliable (McLay, 1989). There is no reliable way of knowing whether patients have received verbal warnings or been involved in accidents. The current 'point' system means that only criminal offences such as speeding are recorded on the drivers licence. Less serious accidents, where there is no police involvement or where the driver is not found to be at fault, are difficult to trace.

There have been no large follow up studies of brain damaged drivers in this country. The largest, by Simms and O'Toole (1994) followed up 307 patients (180 CVA, 88 TBI and 39 MS), one year after 'fitness to drive' assessment by the Banstead Mobility Centre. In a questionnaire survey, people were asked about their current driving status and accident involvement. Only 143 questionnaires (47%) were returned. Of the 87 people reported to be driving, only 19 responded to the request for details of driving accidents and incidents. No incidents were reported and only 4 drivers admitted to an accident.

1.1.2.1 Limitations of the research

Many attempts to calculate risk by follow up are seriously limited. Often they are unrepresentative, with inferences drawn from tiny samples or biased by failing to adjust risk estimates for driving exposure (Hazelkorn et al. 1998; Katz et al., 1990). In studies where this is done, risk estimates are greatly increased (Evans 1988). Follow up studies in the Netherlands and the United States that infer little or no increased risk imposed by brain damaged drivers are probably misleading and unrepresentative of drivers in Great Britain. Many hospital rehabilitation facilities in the Netherlands and America offer driver evaluation programmes (where patients are tested and re-trained before returning to the road), therefore unfit or borderline drivers do not necessarily feature in risks identified at follow up. In Great Britain, where there is no provision for driver retraining and where only a minority of patients undergo any form of evaluation, risks may be greater. Furthermore in the Netherlands, provision is made for 'restricted' driving, whereby certain conditions are imposed on the driver's licence. By comparison in Britain, a licence to drive means driving on any road at any time.

1.1.2.2 Section summary

There may be an increased risk of accidents among brain damaged drivers. However, the extent of this is almost impossible to identify. Studies attempting to do so are limited in design, by sample size (in single diagnostic groups) or because they combine different diagnostic groups of patients, thus obscuring important differences which may lie between them. Diagnosis specific information remains patchy and inconclusive.

Even if risks are no greater, deciding who can drive remains a problem. A reliable method of determining safe from unsafe drivers is needed. In the light of the findings by Johannson et al (1997), Adler (1996) and Evans (1988), the suggestion that no increased risk is posed by groups of neurologically impaired drivers other than those with dementia is perhaps optimistic. However, if all neurologically impaired drivers were precluded from driving, accident risks would be very low but at great personal (psychological and social) expense.

1.1.3 The legal requirements for driving

In Great Britain the Driver and Vehicle Licensing Agency (DVLA) is responsible for decisions concerning fitness to drive. However, it is the licence holder's 'duty' to notify DVLA of a relevant or prospective disability that may now, or in the future, affect their safety to drive a car (DVLA, 1998). Relevant disabilities include those listed in the regulations, plus others, which are likely to be a 'source of danger' to the public. Prospective disabilities are those which may become relevant in the future (either intermittently or progressively) and affect safe driving.

Once notified, the DVLA instigates a process of enquiry. The patient (licence holder) and the patient's General Practitioner (GP) are sent detailed questionnaires (see Appendix 1) asking for information about the patient's condition and how it may affect him as a driver. During a medical assessment in the confines of the GP surgery, it may be feasible to establish whether patients have physical disabilities which may affect the ability to drive. The GP may also have access to equipment to determine whether patients have the necessary vision for driving, (ability to read a registration mark 20.5 metres away and a visual field of at least 120° on the horizontal and no significant defect in the binocular field encroaching within 20° of fixation above or blow the horizontal meridian, DVLA, 1998) but it is unlikely that any form of cognitive assessment takes place.

Completed questionnaires returned by the patient to the DVLA are cross-checked for accuracy with those of the GP. Sometimes a medical specialist, such as a neurologist or ophthalmologist, is consulted when specific detail is required. Doctors are given guidance from the DVLA in the form of a handbook, the "At a Glance Guide to the Medical Aspects of fitness to Drive" (DVLA, 1998). This specifies the medical standards of fitness to drive for ordinary (Group 1) licences, i.e. motor cars and motorbikes and Group 2 (LGV/PCV, large lorries, buses, medium sized goods vehicles and 9-16 seater minibuses. Guidance is specific to the disability in question. For example, someone suffering from a chronic neurological disorder, such as Parkinson's disease or multiple sclerosis may retain a 'Till 70' licence, providing medical assessment confirms that driving is not impaired. Short period licences of 1, 2 or 3 years are occasionally issued. Sometimes patients need vehicle adaptations in order to drive, in which case the licence is restricted to "with controls to suit the disability". Someone who has suffered a serious head injury must have between six and twelve months off driving. However, in milder cases, where consciousness is lost without complications and clinical recovery is "full and complete", driving may resume without notifying the DVLA. Ordinary licence (group 1) entitlements for patients with acquired neurological disabilities represented in this study are summarised in Table 1.

Table 1.0: **Summary of medical standards of fitness to drive for patients with acquired neurological disability (DVLA 1999).**

NEUROLOGICAL DISORDERS	GROUP 1 ENTITLEMENT
<u>CHRONIC NEUROLOGICAL DISORDERS</u> E.g. Parkinson's Disease, MS, muscle and movement disorders including motor neurone disease, likely to affect vehicle control because of impairment of co-ordination and muscle power.	Provided medical assessment confirms that driving performance is not impaired retain Till 70. Should the driver require a restriction to certain controls, the law requires this to be specified on the licence. A short period licence may be required.
<u>CEREBROVASCULAR DISEASE:</u> including stroke due to occlusive vascular disease, spontaneous intracerebral haemorrhage. Transient Ischaemic Attack (TIA)	At least one month off driving after the event. When clinical recovery is satisfactory may restart driving. Till 70 retained provided no significant residual disability. Should residual limb disability require a restriction to certain controls, this will need to be specified on the licence. (The driver receives an explanatory letter "Driving and Strokes" from the DVLA). At least one month off as for stroke. If TIA's have been recurrent and frequent, a 3-month period free of attacks may be required.
<u>SERIOUS HEAD INJURY</u>	6-12 months off driving. Where consciousness is lost without complications, driving may resume without notifying the DVLA. More specific advice is given for intracranial haematomas.
<u>BRAIN TUMOURS</u>	Advice specific to site, severity and nature (malignant/non malignant) of tumour and type of treatment (i.e. surgical, radiotherapy or no treatment) e.g. for pituitary tumours requiring craniotomy, driving may resume when clinically recovered. For grade 3 and 4 gliomas, at least 2 years or more off driving.
<u>SUBARACHNOID HEMORRHAGE</u>	Where no cause is found, driving may resume when clinically recovered. When due to intracerebral

	aneurysm, advice depends on aneurysm site and treatment (e.g. surgical, embolisation, no treatment) and varies between awaiting full clinical recovery, 6 months and 1 year off driving.
DEMENTIA	It is extremely difficult to assess driving ability in those with dementia. Those who have poor short-term memory, disorientation, lack of insight and judgement are almost certainly not fit to drive. Disorders of attention are important. In early dementia when sufficient skills may be retained a formal driving assessment may be necessary.

Although comprehensive in the range of disabilities covered, these guidelines emphasise medical complications resulting from neurological disabilities and underplay the neurobehavioural and cognitive deficits that are part of them. Since these deficits may affect a persons fitness to drive more than physical disabilities (Barnes, 1997), it could be argued that the guidelines lack important detail. In particular the terms 'full and complete clinical recovery' suggest consideration of factors which are visually apparent or that can be established on the basis of a brief 'medical assessment'. Such an assessment may fail to take into account hidden factors such as perceptual and cognitive impairments, or behavioural change.

The section on disabled drivers, which refers to 'impairment of cognitive function', suggests that the ability to cope with activities of daily living (ADL) competently may be used as a yardstick. This follows studies of demented drivers (O'Neill et al, 1992) where ADL measures were found to have some predictive capacity. However, evidence to support their use among other cognitively impaired drivers, such as stroke or head injury is lacking. The section also refers to in car assessments on private circuits as a means of checking for visual inattention, easy distractibility and difficulty performing multiple tasks, in spite of growing evidence to suggest that off road driving tests barely test more than car handling skills and bear little relation to on-road driving (Brooke et al., 1992; Simms, 1994; Sivak et al., 1981). The guidelines allude to reaction time, memory, concentration and confidence impairments as likely to affect driving performance. These may also be more relevant to demented drivers than those with other acquired neurological disabilities (McKenna, 1998).

Even detailed medical examinations carried out specifically to determine fitness to drive may be inadequate. In a study by Johansson et al., (1996) tests of visual acuity and the standard medical examination were not able to distinguish between a group of older drivers who had temporarily had their licenses suspended following involvement in crashes and controls. The authors found that even mild cognitive impairment contributed to the risk of losing a license because of crashes but the standard medical examination (compulsory in many countries) was not sufficient to identify those with increased crash risk. They concluded that physicians alone are not good at identifying saying who is and who is not fit to drive, findings supported by Fox et al., (1992) and Heikkila et al., (1998).

1.1.4 Specialist driving assessment centres

Some patients may be referred to specialist driving assessment centres for advice concerning fitness to drive. These centres offer independent advice tailored to individual needs, for example, specific advice on adaptive equipment or full medical and visual assessment. Referral to these centres may be made by the DVLA, Motability (a charitable organisation that operates a vehicle lease hire service to people receiving the mobility component of disability living allowance), GPs, therapists or medical specialists but most patients refer themselves. There are currently 16 centres in Great Britain; 13 belong to the Forum of Regional Mobility Centres which sets standards for assessment. The Forum of Regional Mobility Centres is a network of organisations, which aims to help elderly and disabled people achieve independent mobility as drivers passengers and wheelchair users.

To become Forum members, centres must first be accredited. This involves rigorous examination of their assessment technique, staff training and facilities. The DVLA only refer patients to forum accredited centres, except in exceptional circumstances (such as geographical location) when they may be referred to non accredited centres.

Assessment procedures and expertise varies from one centre to the next. Some employ therapists, technicians, optometrists and qualified driving instructors and have access to psychologists and doctors; others are manned purely by technicians and clerical staff (Frye, 1995). Centres also differ in terms of the length of the assessment, the equipment they have available and assessment cost (Frye, 1995). Criteria are not fixed but rely on the clinical experience of the assessors. More importantly, many centres offer no form of cognitive or visual assessment. Location, long waiting lists and cost (ranging from no charge to £130.00 per assessment) deter many disabled people from seeking this sort of specialist advice for themselves. Instead they look to their families, GPs and other health professionals for advice (Priddy et al., 1990; Fisk et al, 1997). Many continue, resume or stop driving altogether without specific recommendations from the licensing authorities.

Out of 51 stroke patients who were driving in the three months before their stroke, followed up in Nottingham, 30% had resumed driving without assessment or advice (Nouri, 1988). In the United States, Fisk and colleagues (1997) surveyed a convenience sample of 290 stroke patients between three months and six years after stroke. They also found many had returned to driving without any form of re-evaluation or advice.

The proportion seeking professional advice among people with Parkinson's disease is low. In a study by Ritter and Steinberg (1979), only 23% of patients had been told about their suitability to drive by a doctor. McLay (1989) surveyed 15 members of Branches of the Parkinson's Disease Society and found that only a third had notified the DVLA of their disorder, although most had given up driving.

1.1.5 The question of 'fitness to drive'

With little information about actual risks posed, the assumption is that people with acquired brain damage may be at increased risk of accidents by the very nature of their disability. i.e. cognitive and perceptual deficits that occur suddenly (CVA, TBI) or deteriorate gradually (Parkinson's disease, dementia) imply a reduction in the skills required for safe driving. The logical response to this concern, is to determine which skills are impaired and to what extent, so that people clearly unfit to drive on the basis of their cognitive deficits, can be prevented from driving.

This theory is supported by research into brain damaged drivers suggesting that as a group, they show significant deficit in driving skills.

In 1983, Wilson and Smith compared the on road driving performance of stroke patients to 'normal' controls. They found that stroke patients had difficulty in road positioning, getting on and off motorways, handling intersections and doing two things at the same time in an emergency. Sivak (1981) compared 23 brain damaged patients with eight spinal cord injured and ten able bodied drivers. Patients were tested on perceptual and cognitive tests, driving in a car park and on the road over a set route. They found that patients who performed well on cognitive and perceptual tests, tended to show good driving performance and that certain tests were good predictors of driving performance in patients with and without brain damage. They concluded that the driving problems were likely to have resulted from deficits in perceptual and cognitive skill. Tests which correlated highest with on-road driving included tests of perceptual discrimination (Picture Completion), Stereodepth (Titmus Vision Tester) and sequencing (Picture Arrangement). An important finding was that none of the closed course measures correlated with the on-road test score, suggesting they measure different abilities.

In a review, van Zomeren and colleagues (1987) found brain damaged patients showed poor driving skill (for example poor judgement of traffic situations) and risky behaviour (such as impulsivity) but that traditional psychological tests had insufficient predictive value for driving. They criticised testing procedures that emphasise car handling, control use, mirrors and technical adaptations (driving on the operational level) and indicated the need for assessment techniques to emphasise higher cognitive levels in driving, such as decision making in complex traffic situations and inclement weather or decisions involving journey planning (tactical and strategic level driving).

Simms (1994) carried out a comprehensive review of cognitive assessment for driving following brain damage. She looked at 30 studies, 24 linking the scores of cognitive assessment to driving and six reporting structured training programmes. She found that certain individual tests correlated with driving performance (tests of visuo-perceptual and attentional skills and memory) and that higher order processes were more likely to be determinants of safe driving but were less easily observed or measured. She found no evidence to suggest that either reaction times or off road driving predict driving in traffic.

Simms and O'Toole (1994) suggested that groups of cognitive tests are more likely to be predictive than individual test scores. They were able to accurately predict driving test performance in 80% of cases using a combination of test scores (primarily assessing higher order processes associated with planning and organisation), a full visual assessment and factors such as driving experience and age. However, rather than being a pragmatic trial attempting to predict fitness to drive, this was a retrospective review of assessments carried out at the Banstead Mobility Centre, where, as part of routine procedure, driving assessors are privy to cognitive assessment results. Therefore the on road evaluation (used as the criterion measure) was not an independent rating of the patients' fitness to drive.

Studies by Engum and colleagues (1988, 1989, 1990) who developed the Cognitive Behavioural Drivers Inventory (CBDI) found this to be predictive of on-road driving among brain damaged people, in 89% of cases. The CBDI is a composite index that includes both computerised and standard psychometric tests of attention, reasoning ability (Picture Completion and Digit Symbol - WAIS-R, Trail Making Test), concentration, visual scanning, visuo-motor co-ordination and visual sequencing plus non-cognitive tests of braking reaction time, visual field and visual acuity. One problem with the CBDI is the difficulty making predictions for those patients who fall into the borderline range of scores (between 47 and 52). In particular, two groups of 'problem' patients are identified; elderly patients in whom driving is often judged better than the CBDI would predict and young closed head injured patients who perform well on the CBDI but fail on the road (Lambert and Engum, 1992).

Lundqvist and colleagues (1997) compared the performance of 29 brain damaged patients and 29 matched controls on a neuropsychological test battery, driving in an advanced simulator and driving on the road. They found patients performed significantly worse on psychometric tests, in particular tests of cognition and executive function and during simulated driving in unpredictable situations. Patients took longer to react and had difficulty allocating resources to a secondary task (Modified Listening Span Test). Patients also performed significantly worse on the road (41% failed the on-road test). The neuropsychological test battery correctly classified 80% of patients. The Cognitive Capacity test, a measure of cognitive speed and attention, was the most significant overall predictor of driving ability. Although the sample was small the findings support the need for neuropsychological tests which measure attention, information processing speed and executive functions.

Most of these studies include mixed diagnostic groups of patients, based on the assumption that brain damaged patients share common cognitive deficits which underpin the skills necessary for driving and thus affect driving safety. If this is true, then the patient's diagnosis should not matter. However, documented difficulty in predicting for certain groups (Lambert and Engum, 1992, Simms and O'Toole 1994, Brouwer and Withaar, 1997) suggests important diagnostic differences may exist.

1.1.5.1 Section summary

Research has shown that brain damaged patients have deficient driving skills, which are reflected by poor performance on traditional psychometric tests. While it seems likely that cognitive and perceptual skills are essential for driving, it remains unclear exactly which deficits make someone unsafe or which measures should be used to detect them.

One problem with studies involving brain damaged drivers is that on-road driving is not always used as the criterion measure or 'gold standard'. Where it is, it is not always sufficiently cognitively demanding, resulting in poor predictability on the part of cognitive tests. Another problem is that studies have tended to rely on correlation between cognitive test and driving performance rather than clear cut offs in cognitive test scores as indicators of fitness to drive. Studies combining groups of cognitive tests scores have had greater success but even combinations with high sensitivity and specificity tend to encounter problems in prediction for some groups of patients, such as TBI. Others have attempted to determine driving safety by simulation.

1.1.6 Off-road evaluations and driving simulation

Many early attempts to predict fitness to drive relied on off-road evaluations (combinations of neuropsychological, visual, physical and medical appraisals), which, whilst eliciting useful information, do not equate to nor replace the need for on-road testing (Galski et al., 1993; Jones et al. 1983; Sivak et al., 1981). In fact, they may be unreliable and lack validity (Galski et al., 1997).

In a review of 300 patients seen as part of a driver assessment service in New Zealand, Jones et al. (1983) found off-road testing (using a computerised visual preview tracking test and computerised reaction times test, plus tests of vision) did not equate to on-road testing and only complimented, rather than replaced the need for it. Galski and colleagues (1993) tested 106 patients on average nine months after injury (range one to 106 months) on a battery of psychometric tests, a driving simulator and an on-road test. Tests included selective attention, sustained attention, visuomotor co-ordination and tests of executive abilities. Using discriminant function analysis to predict failure on the road, they found combinations of test factors (cognitive tests, simulator assessments and on-road evaluations) differentiated between safe and unsafe drivers with greater and lesser degrees of sensitivity and specificity when combined with observable behaviour ratings (impulsivity, confusion, anxiety, inattention, slowness, following directions, executive functioning). The most sensitive to failure were off-road driving plus behaviour ratings and the most specific were the cognitive test results plus simulator assessments. Unfortunately, some of the patients in the Galski et al., (1993) study were novice drivers, indicating their ability to learn to drive rather than their driving ability was used as an outcome measure. This probably explains the sensitivity of off road driving for detecting failure in this study. Although sophisticated simulators may measure more than stopping distances, braking errors and steering (they may also provide an opportunity to observe driver related behaviours such as anticipatory braking and defensive steering (Galski et al., 1997)), what they cannot do is consider the reasons for performance errors or the deficits which explain them. As a result, people whose deficits are not important in real life driving may be precluded from driving and those whose deficits are not detected by simulator performance could be passed (Galski et al., 1997). Even simulators with good face validity such as those using moving films, do not capture the true, behavioural, cognitive and perceptual demands of real life driving nor the change in requirements needed in varying situations (such as inclement weather or congestion). This lack of interaction means patients do not get the 'feel' of real life driving (Galski et al., 1997).

More sophisticated efforts to simulate real life driving have been thwarted by problems similar to those experienced by pilots in gravity training (the sickness caused by moving film situations when the driver is seated in a static vehicle, Goodenough, 1976) and now pose ethical problems in consenting patients for studies.

In Great Britain, not all specialist driving centres have access to driving simulators. Where they do, they are often little more than static rigs, designed to measure braking forces, steering torque and reaction times, or to take measurements for vehicle adaptations. Whilst useful in their own right, they do not substitute the need for on-road testing (Nouri, 1991).

Few studies have related performance on a driving simulator to passing or failing an on-road test. Those which have, found little correspondence between the outcomes (Galski et al. 1993; Hopewell and Price, 1985; Jones et al., 1983; Sivak et al., 1981). In a study of 40 stroke patients, Nouri and Tinson (1988) compared the ratings (Good, Average, Borderline, Below Standard) made by a driving technician on the basis of an assessment on a computerised static rig, to patients' performance on a road test with a BSM instructor over a set route. The road test was graded as pass, borderline or fail. Agreement between simulator grades and driving outcome was examined using the Kappa Coefficient (Cohen, 1960). Agreement (using Fleiss' (1981) definition) was poor (k=0.29). Gradings awarded purely on the basis of simulator assessments were not good predictors. There was a discrepancy in a third of all cases. Of concern were five patients awarded a pass on the simulator but who failed on the road and three rated as below standard on the simulator who passed on the road. Disagreement between the simulator technician's ratings and the on road test results was high among the more severely affected who were judged more favourably by the technician, on the basis of simulated reaction time, than on the more complex real-life driving. The authors suggested that perceptual problems are overlooked by the driving simulator (as suggested by the severity). The findings supported those of Montgomery and Hunter (1987) who also found discrepancies between simulated and in-car reaction times with neurologically impaired subjects.

More recently, Lundqvist and colleagues (1997) compared the performance of 29 brain damaged patients and 29 matched controls on a simulated driving task and driving on the road. They found patients performed significantly worse than controls during simulated driving in unpredictable situations, took longer to react and had difficulty allocating resources to a secondary task (Modified Listening Span Test). Patients also performed significantly worse on the road (41% failed the on-road test). However, they found that brain damaged patients were able to compensate for their cognitive deficits during the simulator task. Patients gave priority to driving when overloaded by a secondary task (Modified Listening Span Test) and increased their safety margins when faced with an unpredictable situation. In a comparison of 30 stoke patients to matched controls on the same task, Lundqvist et al., (2000) found patients performed as well as controls on the driving simulator but again had significantly greater difficulty allocating processing resources to the secondary information processing task during simulated driving. Patients also had significantly worse driving skill when tested on the road. The authors attributed the inability of simulator driving to distinguish between patients and controls to inexperience (i.e. subjects compensated for their inability by driving very cautiously) and recommend use of a more complex and unpredictable task. By itself, the simulator was unable to predict individual on road performance.

Advocates of the use of driving simulators cite the supposed risk to society if neurologically impaired drivers are tested on the road (Hopewell and Van Zomeren, 1990) and failure of other predictive methods to be sufficiently related to driving (Korteling and Kaptein, 1996). Yet it could be argued that the conservative bias of most cognitive tests (more fit drivers are prevented from driving than unfit drivers permitted to drive) means it is more likely that those who are or could become fit to drive are prevented from doing so (Brouwer and

Withaar, 1997; Galski et al., 1997). Furthermore, if a risk to society did exist, then the short term risk of testing the patient in a dual controlled vehicle is better than the long term risk of putting an unsafe driver on the road (Nouri, 1991). The future development of more sophisticated simulators where patients are placed in artificially dangerous situations and bombarded by hazards with reduced decision making time, could assist in overcoming the failure of on road tests to encounter situations that are sufficiently cognitively demanding.

1.1.6.1 Section summary

Research to date suggests that simulators are appropriate for measuring stopping distances, braking errors and steering. They may also provide an opportunity to observe driver related behaviours. However, they fail to capture the true changing demands of real life driving and as such, they are unreliable and do not substitute the need for on-road testing in neurologically impaired drivers.

1.1.7 Driving Models

Models are important for understanding driving behaviours and the factors underlying research. Without them, post hoc explanations are often proposed to explain the relationships between predictors and criterion measures. Models help to understand and explain underlying mechanisms and distinguish between concepts such as attention (e.g. sustained, selective and divided attention). In this way they facilitate the communication of findings and progression of knowledge (Ranney, 1994).

Early models of driving included accident proneness (Falmer and Chambers, 1939; Hakkinen, 1976; Shaw and Sichel, 1971; Sivak et al., 1981); behavioural task analysis or motivational models (McKnight and Adams, 1971; Naatanen and Summala, 1976) and information processing (Galski et al., 1992; Rumar, 1982). Although useful for considering which cognitive functions are affected by brain damage (Simms, 1994), these models were limited and failed to account for the automatic nature of the driving task, i.e. the fact that many driving behaviours are carried out with little conscious thought (McKenna, 1998; Ranney 1994). The distinction between automatic behaviour, which is fast and effortless and controlled processing, which is slow and demands attentional resources, is important, particularly in relation to brain damaged drivers. Automaticity is situation specific, that is, it depends on the current driving situation and all previously encountered situations. Situations that are new or unexpected differ from previous experience and thus disrupt automatic processing, calling for controlled responses. Uncertainty is also believed to trigger this disruption. It is thought that when uncertainty increases beyond a certain threshold, drivers switch from passive noticing of unspecified stimuli to active goal directed visual scanning (Ranney, 1994). As a result of cognitive disabilities, neurologically impaired drivers may have lower thresholds for activating this control mechanism. For example memory dysfunction could theoretically affect previous driving experience and route familiarity, thus reducing the threshold and increasing dependence on controlled rather than automatic processing (Ranney, 1994). Deficits in sustained or selective attention and executive dysfunction may affect the ability to cope with new or demanding driving situations. The hierarchical model of Driving Task Performance (Michon, 1979; 1985), together with an appreciation of the automaticity concept, is regarded as a suitable tool to understand driving behaviour and explain attentional and control mechanisms (McKenna, 1998; Ranney, 1994; Simms and O'Toole 1994; Van Zomeren et al., 1987).

The Michon model attempts to integrate individual differences in cognitive style, decision making, driving style, motivation, attitudes and personality with cognition (Reason et al., 1991; West et al., 1992). It involves concurrent activity at three levels, strategic, tactical and operational. (Figure 1). Decisions made at the higher levels determine cognitive load at lower levels, for example the decision to change lane at the tactical level increases cognitive load at the operational level by increasing the number of actions required.

Figure 1 : The Hierarchical Model of Driving Task Performance, (Michon, 1979, 1985)

The Hierarchical Model of
Task Performance in Car Driving

Strategical	planning, decision making (before driving)
⇩	
Tactical	on the road decisions e.g. slow down
⇩	
Operational	perceptions and actions that occur during driving

The strategic level is primarily concerned with planning and thus allows the driver to compensate for impairments which may affect driving at the lower levels e.g.

by avoiding night driving. It is thought that on-road tests do not tap strategic levels of driving as decisions are made before driving starts (Van Zomeren et. al., 1987). The tactical level is concerned with behaviour and decisions made during driving, such as whether to reduce speed or turn on headlights when visibility is reduced by rain. Time pressure is greater at this level, for example maintaining optimum stopping distances when driving in the rain.

The operational level involves basic car handling skills such as braking or steering. Time pressure is high and the risk of danger most acute.

Time is an important feature of this model. Pressure increases as the levels decrease, so for decisions made at the strategic level, time pressure is low. Such decisions might be those made before the journey begins, for example choice of route, whether to avoid rush hour or whether or not to drive at all. A decision to slow down in a built up area (tactical level), made early, allows more time for actions, whereas sudden or late decisions reduce the amount of time for actions (e.g. braking if a child runs into the road).

1.1.7.1 Section summary

The Michon model and concepts of automaticity are useful for understanding the behaviour of neurologically impaired drivers and for interpreting and communicating research findings. Any driving assessment must consider operational level driving but those measuring driving at tactical and strategic levels are more likely to correspond to cognitive test scores and better reflect the types of decisions faced by the neurologically impaired driver in real life.

1.2 Definition of fitness to drive

Car driving is a learned activity demanding complex interaction of physical, cognitive, perceptual and psychological skills (Galski et al., 1992). Brouwer and Withaar (1997) define someone who is fit to drive as someone who can maintain control of their behaviour, has sufficient perceptual, cognitive and motor abilities to be able to drive i.e. to "acquire and apply important driving skills" and who is socially responsible (for example, someone who would not drink alcohol and drive). However, Engum and co-workers (1988;1989;1990) define fitness to drive as "practical fitness to drive as judged by an on-road assessment".

In Great Britain the question of fitness to drive has greater ramifications than in some other countries. For example, in the Netherlands, fitness to drive, refers to a process of assessment to decide who may be fit to re-take a standard road test. It is also possible to issue restricted licences, which permit people to drive only on certain roads at certain times. In some American States detailed driving evaluation programmes run by Occupational Therapists trained specifically to be driver assessors, form part of routine hospital rehabilitation. Hence, the question is twofold; initially, 'Is this driver suitable for re-training?' and following re-training, 'Are they safe to drive?'

In Britain restricted licences do not exist. Fitness to drive granted by the DVLA, means fitness to drive anywhere, on any road. There are no re-training programmes. Therefore, it is vital that cognitive tests, medical assessments and on-road evaluations which influence decisions concerning fitness to drive are valid and reliable.

1.3 Cognitive deficits affecting fitness to drive

The term cognition refers to mental abilities that depend on cortical brain function. These include language, visual perception, memory and mental function. Cognition is concerned with how a person receives stores and organises, makes sense of and responds to incoming stimuli. Cognition refers to a wide range of behaviours which are linked in that they require conscious thought (Lester, 1991) although with practice many of these can be carried out automatically. Cognitive disability refers to a brain dysfunction, which restricts cognitive performance to below the anticipated 'normal' range.

Cognitive deficits which may affect the ability to drive include attention, slowed reaction time, distractibility, disinhibition, impulsivity, slowed information processing speed, poor reasoning abilities and impaired executive function. Other features of neurologically impaired people that may affect driving (Engum et al, 1988) are memory deficits, poor sequencing ability and visual and perceptual deficits such as spatial disorientation, depth perception, hemi-inattention and figure ground discrimination. Based on research to date, some deficits seem to be more important than others. In particular, deficits of attention and concentration, information processing speed, deficits in reasoning and executive abilities and visuo-spatial deficits (Brouwer and Withaar, 1997; Lundqvist et al., 1997; 2000). Clear distinction between these abilities in relation to the driving task is virtually impossible, since many driving situations call upon a combination of skills.

1.3.1 Visuo-spatial deficits and perceptual skills

These include visual scanning, visuo-motor co-ordination, visual sequencing, spatial orientation, poor depth perception, figure ground discrimination, hemi-inattention, impaired attention to detail and the inability to differentiate essential from non essential details (Engum et al., 1988; Simms 1985). Perceptual skills determine how easily a driver notices cues when driving, including those that lie ahead (e.g. brake lights, traffic lights, and road signs) and those in the peripheral vision such as cyclists approaching from behind, cars pulling out or a child running into the road (Simms 1985). It is postulated that deficits in perceptual abilities could result in failure to notice pedestrians or cars approaching from the left (hemi-inattention) or difficulty in car positioning, overtaking and reversing Visuospatial skills are likely to relate to the ability to judge space and distance when monitoring oncoming cars and parking (Doege et al., 1986). Among attempts to predict fitness to drive, those who found a significant relationship between on road driving and performance on tests of spatial abilities and/or perceptual skills include Mazer et al., (1998), Nouri et al., (1987), Nouri and Lincoln, (1992) and Sivak et al., (1981).

1.3.2 Attentional deficits and concentration

The lack of a clear definition of attention in the literature means that it is sometimes categorised within the broader concept of information processing but most regard it as a system where processing occurs in a sequential series of stages within the brain systems that involve attention. Disorders result from lesions involving any part of this system but quite often damage to one part of the system affects other aspects of attention (Lezak, 1995). Different aspects of attention have different roles; i) Immediate span of attention concerns how much information can be grasped at once. This aspect tends to resist the effect of ageing and many brain disorders (Lezak, 1995). Other aspects, more susceptible to damage are ii) selective or focussed attention, which involves the ability to highlight one or two important stimuli, whilst warding off competing distractions. This is also commonly referred to as concentration. iii) Sustained attention refers to the capacity to maintain attentional activity over a period of time (Van Zomeren and Brouwer, 1990). iv) Divided attention involves the ability to respond to more than one task at a time (this is sensitive to brain damage) and v) alternating attention allows for shifts in focus and task.

A predominant feature of the attentional system is that it has limited capacity, such that only a limited amount of processing can take place at any time. Therefore attentional tasks calling upon the same processing requirements, such as watching television and listening to the radio interfere with each other. Attentional capacity is thought to be essential in switching attentional focus to react and respond to stimuli. Failure to sustain attention is thought to explain errors at intersections and merging errors among older drivers (Odenheimer, 1993).

In driving, many attentional tasks are considered to be automatic or highly over-learned, such that most drivers could easily listen to the radio whilst driving on a familiar route (McKenna, 1998). However individual differences in attentional capacity do exist. In brain damaged patients with attentional deficits, the over-learned or 'automatic' nature of the driving task is brought into question (Ranney, 1994).

The ability to switch the focus of attention in order to react and respond to environmental stimuli is thought to be essential in driving. For example noticing the cyclist approaching on the inside when turning left (a major contributor to crashes involving older drivers and bike riders (Parasuraman and Nestor, 1991).

According to Van Zomeren and Brouwer (1987), lapses of attention amongst TBI patients are no more frequent than in healthy controls. However, the fact that attention is an important factor in safe driving is not disputed (Alm, 1989; Brouwer and Withaar, 1997). Brooke et al, (1992) found that TBI patients who failed an on-road test suffered from visuospatial and attentional deficits resulting in extreme slowness or distractibility. It is thought that distractibility can explain driving errors at intersections and sites of merging traffic among demented drivers (Odenheimer, 1993). Memory problems are thought to be relevant when there is a change in routine, such as a detour or specific instruction e.g. slowing down when approaching road works (Odenheimer, 1993).

1.3.3 Delayed information processing ability

Information processing ability and divided attention have been delineated as important skills for elderly drivers (Ponds et al., 1988, Ranney, 1994) yet both decline as part of the normal ageing process. While it is thought that mild to moderate slowness in information processing ability can be well accommodated because the driving task has room for compensatory behaviour (both through the hierarchical organisation of the driving task (Michon, 1989) and because of over-learned, cognitive, perceptual and motor skills (Brouwer et al., 1990; Brouwer and Ponds, 1994) it may pose a problem when it is very extreme. It is only when time for decision making is reduced by environmental conditions such as traffic density, visibility and weather that speed of information processing becomes more important. Studies that control for these variables or restrict the driving task, are unlikely to find significant relationships between information processing ability and driving. Among studies of brain damaged patients using on-road testing as the criterion measure, tests of information processing speed have been found to predict passing or failing (Engum et al., 1988; 1989; 1990; Lundqvist et al., 1997; 2000).

1.3.4 Impaired judgement, reasoning and executive abilities

The ability to maintain a safe distance, and position the car in the road, to navigate roundabouts and intersections and to plan a journey are thought to depend on intact reasoning abilities (Alm, 1989; Hakamies-Blomqvist, 1996). The ability to adapt speed to traffic conditions and to estimate risk have also been attributed to reasoning (Engum et al., 1988). The ability to control and regulate behaviour are executive abilities directly related to driving (Engum et al., 1988; Brouwer and Withaar, 1997). Gurgold and Harden (1978) found impairments of judgement, reasoning and the inability to follow directions prevented patients from driving. Sivak and colleagues (1981) also found a significant relationship between tests of reasoning abilities and performance on the road, findings supported by Brooke et al. (1992), Engum et al., (1988; 1989;1990), Fattal et al., (1998), Lambert and Engum (1992), Lundqvist et al., (2000), Mazer et al (1998), Nouri et al., (1987) and Nouri and Lincoln 1992).

1.4 Problems with assessing fitness to drive.

1.4.1 Lack of empirical evidence

In a review of the literature Brouwer and Withaar (1997) identified two important problems with attempting to answer the 'fitness to drive' question. Firstly, in the medico legal sense, criteria used to establish 'fitness to drive' are vague and based more on common sense than empirical evidence. Secondly, there is a lack of evidence to suggest that neurological conditions affect safety to drive or that fitness to drive can be assessed medically and/ or psychologically in a valid and reliable way (Monga et al., 1997).

1.4.2 Sample size and diagnosis

Many studies attempting to predict fitness to drive have been small (30 ± 8) or have combined patients with brain damage due to different causes, thereby obscuring important diagnostic differences and resulting in inaccurate and possibly clinically meaningless predictions. Later studies have recognised important diagnostic differences between groups of brain damaged patients (Lambert and Engum, 1992; Simms and O'Toole, 1994). These studies have yielded more meaningful, though still inconclusive results (Korteling and Kaptein, 1996).

1.4.3 Measures of driving

Measures of driving vary so greatly between studies that any clear conclusions about the predictive validity of cognitive tests are difficult to identify (Simms, 1994). Some studies use in car driving as the criterion variable but differ in terms of whether driving assessments took place on the public road (Brooke et al., 1992; Engum et al. 1988; 1989; 1990; Nouri and Lincoln 1992; Nouri et al., 1987; Van Zomeren et al., 1988) or an off-road track (Gouvier et al., 1989; Sivak et al., 1981). They also differ in terms of the judgement criteria used by examiners and whether the route is set and formalised (where specific driving tasks are defined) or informalised, to allow aspects of driving thought to tap higher order cognitive skills (tactical and strategic levels of driving) to be measured. One problem with studies that restrict driving to an operational level is that the driving test itself may not tap higher order cognitive processes, such as complex attentional abilities, problem solving and high speed information processing, resulting in poor predictability of the cognitive tests (Korteling and Kaptein, 1996). Even where efforts are made to tap the less observable aspects of cognitive functioning, (e.g. anticipation and mental flexibility) that are considered to be more predictive of safe driving (Korteling and Kaptein, 1996; Simms, 1994), it is possible that subjects are not exposed to situations requiring these skills, in a one-off, time-limited test. Given the emphasis on higher order processes (pertaining to hazard perception and risk taking) among normal drivers (McKenna and Crick, 1994, 1991, Quimby et al, 1986, Rumar, 1990, Van der Molen and Botticher, 1987, Wilde, 1982) it would seem important that they are tested amongst those with acquired brain damage.

Other studies have relied solely on simulated driving assessments (Lings and Dupont, 1992; Madeley et al., 1990; Rebok et al., 1990) or other off road evaluations (Galski et al., 1992; 1997; Jones et al, 1983) and some fail to include a driving related criterion altogether (Mitchell et al.,1995).

1.4.4 Clinical dispute

Unfortunately the question of fitness to drive is not straightforward. In fact the whole area of cognitive assessment for driving is fraught with difficulty (McKenna, 1998). There is ongoing dispute about which factors are important and which ones affect a person's fitness as a driver. Although there is little evidence to suggest that brain damaged drivers in general are an increased risk on the road (Dubinsky et al., 1991; Hazelkorn et al, 1998; Knect, 1977; Van Zomeren et al., 1987) this may be because the safe option - not letting people drive, is chosen.

Concern centres on whether the brain damage is likely to affect cognitive skills presumed necessary for driving. However, there are no clear cut answers as to which psychomotor skills, cognitive processes or personality traits are more likely to make an individual a safe driver or an accident risk (Simms, 1994). Discrepancies in the literature concerning cognitive assessment, arise from the disparate ways the question of driving fitness has been tackled. There seem to be two perspectives. From one, cognitive tests are seen as the definitive answer to the fitness to drive question. i.e. could replace the need for on-road testing and prevent unsafe drivers from progressing to an on-road test. Alternatively, they are seen to compliment existing procedures, i.e. as pre-driver screening tools to detect driving related cognitive deficits, which can be used to inform decisions about driving safety and shed light upon practical driving skills (Brooke et al. 1992; Galski et al., 1992; 1997; Simms and O'Toole, 1994). From this perspective, other factors such as age, driving experience and vision are considered alongside the cognitive test results and often included in analyses. Yet from each perspective, attempts to predict fitness to drive have followed a similar pattern, i.e. testing patients on a battery of cognitive tests and comparing the results to on-road driving (the gold standard) or some other driving related criterion (such as off-road testing or simulated driving). One problem is that researchers rarely select the same cognitive tests or measure them against the same criterion. This has resulted in a growing list of potentially useful cognitive test measures (Figure 1.1) but no definitive answers. All seem to generate similar conclusions i.e. that cognitive tests are 'useful'; that tests of higher order processes are better predictors of driving ability but driving tests do not necessarily tap these skills, resulting in poor predictability; that groups of tests are better than individual ones; that other factors, like age, time since onset and driving experience are also important; that vision testing is an important factor; that some groups of patients are harder to predict for than others (especially head injured patients) and that actual on-road testing is important, some say essential.

Thus although a reasonable amount of research has been carried out, the progression of knowledge has been restricted by the research conditions, the sample size, test selection and the driving 'criterion measure', thus restricting generalisability of the findings. Moreover, statistical analysis has often been complex, without clear cut offs for specific patient groups, restricting practical application in a clinical setting. Exactly which impairments result in deficient driving and how important each of these are remains unknown (McKenna, 1998; Simms and O'Toole, 1994; Van Zomeren et al., 1987).

1.5 Normal drivers

One question which frequently arises is whether attempts to predict fitness to drive in brain damaged drivers relate to 'normal' drivers. Although an important issue, research into normal drivers is not particularly concerned with predicting safe from unsafe drivers in the same way. Since this area is well reviewed elsewhere (Lester, 1991) it is not covered here in detail.

Although cognitive skills are thought to be important for driving, reviews have shown poor correlation between cognitive abilities and accident frequency (Lester, 1991; Ranney, 1994). In fact, biographical and exposure factors such as marital status, mileage and socio-economic status and traffic conviction records have been found to be more significant predictors than psychological attributes (Harano et al., 1975). Attempts to predict using aspects of vision and reaction time have found weak or no relationship with accidents (Hills, 1980), which is attributed to the driver's ability to compensate for deficiencies (Ranney, 1994). Even dynamic visual acuity is not thought to be sufficient to identify high risk drivers, although it has prompted more recent research into 'special' groups, such as the elderly (Ball and Owsley, 1991, Ball et al., 1993, Owsley et al., 1991, 1994, 1998). Owsley et al., (1998) found older drivers with a 40% reduction in the Useful Field Of View (UFOV) (which measures decline in visual sensory function, slowed visual processing speed and impaired visual attention skills), to be 2.2 times more likely to crash in the three following years (having accounted for age, sex, race, chronic medical condition, mental status and days driven per week). They attributed this association to difficulty in dividing attention under target durations.

Clear differences in accident rates between novice and more experienced drivers have been attributed to several factors, such as ability to anticipate potentially dangerous traffic situations-Hazard Perception (McKenna and Crick, 1994), misperception of risks and of driving ability (Finn and Bragg, 1986; Matthews and Moran, 1986) and differences in visual search strategies (Chapman and Underwood, 1998; Crundall et al., 1999). However, whilst cognitive abilities underpin these skills, there is little evidence to suggest that traditional psychometric tests have any prospective predictive value among normal drivers (Lester 1991; Quimby et al., 1986; Ranney, 1994).

In retrospective studies of accident prediction, findings have indicated cognitive tests, which are useful in distinguishing driving ability among groups of commercial drivers. The most consistent predictor being selective attention, based on the assumption that rapid switching of attention is required for complex task performance (Avolio et al., 1985; Mihal and Barrett, 1976). However, these findings have not been widely replicated (McKenna et al., 1986). Moreover, the fact that accidents are rare occurrences means many studies are statistically under-powered. Driver errors do not always lead to accidents and because accidents themselves may have multiple causes, (some unrelated to individual driver characteristics) the validity of these retrospective studies is questioned (Fox et al., 1998; Lester, 1991; Ranney, 1994).

One criticism levelled at the Stroke Drivers Screening Assessment (SDSA) is its inability to distinguish between brain damaged and non-brain damaged drivers. In a study by Mitchell et al., (1995) testing 19 demented and 48 control patients on the SDSA, all demented patients and half of the controls failed. However, in Mitchell's study subjects' driving ability was not tested. As such the probability that the elderly controls who failed the SDSA were also unfit to drive, cannot be excluded. In fact Mitchell and colleagues found a decline in SDSA performance after age 77 and a significant correlation between MMSE and SDSA scores in the normal elderly group, suggesting diminished cognitive abilities among controls. In a study by Lundqvist et al., (2000) where 30 stoke patients and matched controls were road tested, six control patients failed the on-road test. The authors attributed this to slowed cognitive processing speed attributable to brain damage and/or chronological ageing.

Clearly the prediction of fitness to drive among non-brain damaged drivers is a separate question. Tests such as the UFOV (Ball and Owsley, 1991) and the

Hazard Perception Test (McKenna and Crick, 1994), which appear useful in differentiating between groups of normal drivers have yet to be validated for brain damaged patients. It is equally inappropriate to suggest that tests developed specifically for brain damaged drivers, such as the SDSA, should be able to distinguish between the driving capabilities of normal drivers. The SDSA is not validated for testing normal drivers and therefore its use for them inappropriate. Studies attempting to do so exhibit design related bias (Lijmer et al., 1999).

1.6 Cognitive/neuropsychological assessment

Driving is a complex activity which calls for the orchestration of many cognitive systems (McKenna, 1998). Cognitive changes including impairments in memory, information processing speed, concentration, attention, depth perception and spatial awareness are all skills thought to be essential for driving (Lambert and Engum, 1992; Lester, 1991). Given that all aspects of driving behaviour are sub-served by neuropsychological processes, which depend on specific functions of the brain, then it is theoretically possible to test for them (McKenna, 1998). Many different tests have been used in attempts to predict fitness to drive (see Figure 1.1 for summary). Those found to have a significant relationship with road test performance include tests of visual perceptual skills such as Picture Completion, tests of motor co-ordination, such as Hand Movements and Pursuit Rotor, tests of language, reasoning and spatial abilities and memory tests (such as Figure Copy and Recall) and those assessing the ability to recognise road signs and road hazards (Simms, 1994).

Depending on how driving ability is actually measured, patterns are now starting to emerge. In studies where the criterion is driving on the public road, on a route that is not set and formalised but informalised to allow for higher order processes to be measured (Fig 1.1, studies in bold), the cognitive abilities which appear to be important predictors of driving skill are visuo-perceptual skills, visuo-motor co-ordination, concentration, attention, reasoning and executive abilities and visual memory recall.

One of the ongoing problems with the use of cognitive tests for driving is their lack of face validity. This is an important consideration in tests relating to driving. The impact of the decision to stop driving may have far reaching consequences. In the event of failure, poor face validity may affect adherence to advice. Another problem is the length of time the tests take to administer, especially when they form part of a battery (Fattal et al., 1998; Galski et al., 1997), or a more comprehensive driving screening assessment (Simms and O'Toole, 1994).

1.6.1 The requirements of a test battery

Ideally, two types of cognitive test battery are needed. Firstly a screening procedure to identify patients who are cognitively fit to resume driving from those needing more detailed assessment at a specialist driving centre. Such a battery could be used to compliment existing procedures and introduce some form of cognitive assessment among brain damaged drivers where currently non-exists. It must be easy to transport and administer and the results easy to interpret by a range of health professionals.

Secondly cognitive tests should form part of a more comprehensive assessment carried out by specialist driving centres, to highlight cognitive deficits, which may be important for driving but are not necessarily detected by the on-road tests. Such a battery could inform outcome decisions based on other assessments.

A test battery should include tests of known predictive validity for driving, which have face validity and together take less than 30 minutes to administer.

Figure 1.1: Cognitive tests shown to have a significant relationship with road test performance among brain damaged drivers

Visual perceptual skills	**Picture completion**	**Sivak et al 1981**, Simms, 1986
	Motor Free Visual Perception Test	**Mazer et al., 1998**
	Stereodepth	**Sivak et al 1981,**
	Perceptual Speed	**Korteling and Kaptein, 1996**
	Cube Copy, 3D Copying	**Nouri et al '87, Nouri & Lincoln '92**
	Block Design (WAIS-R)	Kumar et al., 1991, Galski et al., 1992
	Judgement of Line Orientation	Priddy et al., 1990
Visual Reaction Time	Cognitive Reaction Time	Gouvier et al., 1989
	computerised reaction time	Stokx and Gaillard, '86, **Lundqvist et al, 00**
Driver Performance	Driver Performance Test. (Video)	Gouvier et al., 1989
Visuo Motor Co-ordination	**Hand Movements**	**Simms & O'Toole 1994**
	Pursuit Rotor	**Nouri et al '87, Nouri & Lincoln '92**
	Finger tapping	**Lundqvist et al.,2000**
Language	Token test	Simms & O'Toole 1994
	Aphasia Test	Hartje et al 1989
Visual Scanning/ concentration	**Dot Cancellation**	**Nouri et al . '87, Nouri & Lincoln '92,**
	Star Cancellation	**Fattal et al 1998**
	Single Letter cancellation	**Mazer et al., 1998**
	Double Letter Cancellation	**Mazer et al., 1998**
	Line Bisection Test	**Fattal et al 1998**

Information Processing		
Speed	Digit Symbol [WAIS]	Kumar et al., 1991, **Lundqvist et al '00, Engum et al., '88, 89, 90**
	Oral Digit Symbol	Gouvier et al., 1989
	Simultaneous capacity test (APT)	Lundqvist et. al, '00
Time Estimation	(computerised)	**Korteling and Kaptein, 1996**
	Tactual Performance Test	**Brooke et al, 1992**
Reasoning Ability	Picture Arrangement [WAIS-R]	Sivak et al 1981, Simms 1986, Kumar et al., 1991, Engum '88, '89, '90
	What's in the square?	**Nouri et al '87, Nouri & Lincoln '92**
	Trail Making Test	**Brooke et al, '92, Mazer et al., 1998, Engum et al., '88, '89, '90,** Kumar et al., 1991
	Trail Making A	**Fattal et al 1998**
	Trail Making B	**Lundqvist et al., 1997**
	Ravens Progressive Matrices	**Fattal et al 1998**
	Stroop	Galski et al., '89, **Lundqvist et al, '97**
	Road Sign Recognition	
	Hazard recognition	Nouri et al 87, Nouri & Lincoln '92
Attention	**PASAT**	**Brooke et al, 92, Lundqvist et al, '97**
Memory	**Figure Copy and recall**	**Nouri et al '87, Nouri & Lincoln '92**
	Delayed Verbal Memory	Rothke 1989
	Benton Visual Retention Test	Priddy et al., 1990, **Fattal et al., 1998,** Galski et al, 1989
	Five item recall	**Johannsen et al., 1996**

Key: Tests with predictive validity for on-road performance shown in bold

A further benefit of identifying cognitive deficits, which affect driving performance is that they may respond to rehabilitation and could be incorporated into training. Sivak et al., (1984) showed cognitive deficits could be trained to augment performance. Using pencil and paper activities to increase perceptual skills, they found these were associated with increased driving skill. Similar findings have been illustrated using Dynavision apparatus to train visual scanning, visual attention, awareness and visual motor reaction time across a broad, active visual field. Klavora et al., (1995) showed significant improvement in driving skill in ten stroke patients who were previously judged unsafe. Also, Kewman and co-workers, (1985) trained 13 brain damaged subjects to perform seven driving related manoeuvres (relating to visuo motor and attentional skills) on an off road track in a small scale electric vehicle. They found practice of manoeuvres generalised to driving performance in a standard car. Thus, for the small numbers involved, various strategies involving intensive training of visuo-motor, perceptual and higher order skills appear effective.

The ability to drive safely may also be affected by other symptoms of acquired neurological disability, such as stress and behavioural problems. Whilst the influence they have on the driving task is acknowledged, it is beyond the scope of this study to address these factors.

The question of fitness to drive arises in several conditions. These will be reviewed separately.

1.7 Definition of Stroke

The World Health Organisation defines Stroke as 'rapidly developed clinical signs of focal or global disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than vascular origin' (Aho et al., 1980). Stroke is the result of a disruption in blood supply to the brain, which deprives brain cells of oxygen, causing some to be damaged and others to die (The Stroke Association, 2000). Most often strokes are caused by a blood clot blocking an artery supplying the brain or by bleeding in or around the brain when a vessel bursts.

1.7.1 Incidence and prevalence.

Each year over 100,000 people in England and Wales have a first stroke, about 10,000 of who are below retirement age (Health Survey for England, 1991). Stroke affects 150 in every 100,000 people but this figure increases dramatically with age, with rates as high as 2,000 per 100,000 in those over 85 (Bamford et al., 1988). Stroke is the largest single cause of disability in England and Wales with over 300,000 people affected at any one time (ONS, 1996).

1.7.2 The effects of stroke

Around a third of people who have a stroke die within a year, a third are left with serious disabilities, the remainder makes a good recovery. The disability resulting from stroke (whether temporary or permanent) depends on the site and extent of damage. Patients can experience motor loss (hemiplegia) usually down one side of the body, complete or partial loss of speech, sensory changes, cognitive impairment and emotional disturbance. Singularly or in combination, these impairments can result in a severe loss of functional ability ranging from self care activities such as feeding and toiletting to the more complex 'extended' activities of daily life, like using public transport or driving.

1.7.3 Cognitive deficits in stroke

1.7.3.1 Mental dysfunction

Ebrahim (1985) found that over ten percent of stroke survivors showed some degree of mental impairment six months after the event, with significantly more short term recall problems among those with left sided damage and greater impairment in bilaterally impaired patients. Those with left sided damage tend to experience difficulty in concrete thinking, encounter specific impairments in reading and writing ability and have impaired mathematical ability (Keller and Sutton, 1991). They may also experience motor and oral sequencing problems (Harrington and Haaland, 1992). Patients with right-sided damage may have poor organisational and planning skills, find difficulty in making sense of complex situations and have impaired appreciation for complex verbal information (Lezak, 1995).

1.7.3.2 Language

Speech and language disorders, such as dysphasia and dysarthria are common yet frequently underestimated (Enderby and Phillips, 1986) after stroke, affecting as many as 37% of survivors (Bonita and Anderson, 1983). Although typically seen among patients with left sided damage (Benson, 1993), lesions in various locations have been associated with dysphasia (Warlow et al., 1996). Dysarthria, a result of unilateral, brainstem and cerebellar lesions, often improves spontaneously, whereas dysphasia continues to affect up to 12% of patients, six months after stroke (Wade et al., 1986) with those severely affected having the poorest prognosis.

1.7.3.3 Visual Perception

The most common visuo-perceptual impairments after stroke are visuo spatial impairments such as the inability to localise points in space, defective judgement of direction and distance, defective topographical orientation and unilateral neglect. Although the right hemisphere dominates visuo spatial processing, perceptual impairments have been found to affect as many as 81% of patients with right and 71% of patients with left hemisphere damage one month post onset (Edmans and Lincoln 1987) and persist two years later, irrespective of the side of damage (Edmans et al., 1991). Unilateral neglect (failure to attend to perceptions from one side of the body) occurs more often in those with right-sided lesions. Perceptual deficits show up on tasks involving copying designs, matching and construction and those involving discrimination (Benton and Hécaen, 1970). Problems with spatial orientation and visuospatial memory (getting lost in familiar surroundings) are also experienced by patients with damage in either the right or left hemisphere (Lezak, 1995; Mehta et al., 1989).

1.7.3.4 Memory

Memory deficits following stroke are well documented (Lincoln and Tinson, 1989, Stewart et al., 1996, Tinson and Lincoln, 1987). Stewart et al., (1996) investigated the incidence of memory impairment late after stroke and found that more than a third had significant memory problems in everyday life. Lincoln and Tinson (1989) followed up a series of patients, aged under 80 at one and seven months and found significantly more memory problems among stroke patients than orthopaedic controls. Attention and short term or 'working' memory are more likely to be affected than long term memory and may restrict the amount of information that can be assimilated at any point in time. Verbal memory or verbal fluency deficits, in particular short-term recall, are typical of left hemisphere lesions (Mehta et al., 1989).

1.7.3.5 Section summary

Perceptual and cognitive problems are common after stroke. Their precise nature and distribution depends on the extent and location of brain damage. Cognitive impairments can affect daily life skills, in particular driving. Unlike many other over-learned skills, driving is extremely complex and never completely routine (Fox et al., 1998). The complexity of the driving task raises concerns about whether cognitively impaired stroke patients are safe to drive and the nature and extent of impairments, which make them unsafe.

1.8 Driving after stroke

Stroke patients have cognitive impairments, which may detrimentally affect driving performance (McKenna, 1998; Ranney, 1994; Wilson and Smith, 1983). However, American studies provided little evidence to suggest that those who resume driving after evaluation are less safe than other drivers (Katz et al., 1990; Kumar et al., 1991). Stroke patients may be at decreased risk of crashing by virtue of self imposed restrictions in their driving behaviour (Hazelkorn et al., 1998). Unfortunately in Great Britain thorough assessment of stroke patients' fitness to resume driving is the exception and many resume driving without any advice (Legh-Smith et al., 1986; Nouri, 1988). Even where detailed evaluation does occur, cognitive factors may be overlooked (Frye, 1995).

When compared to normal controls, stroke patients display faulty driving behaviours, which are reflected by poor performance on cognitive tests (Fattal et al., 1998; Hannen et al., 1998; Lundqvist et al., 1997; Lundqvist et al., 2000; Nouri et al., 1987; Nouri and Lincoln, 1993; Sivak et al., 1981; Van Zomeren et al, 1987; Wilson and Smith, 1983). Simms (1985) tested the driving ability of 104 patients (54 right CVA and 50 left CVA) on a series of cognitive tests followed by a practical driving test. She found more severe perceptual impairments among those with right-sided brain damage. However, in this retrospective review of procedures at one specialist driving centre, only five of those with severe impairments were considered unsafe to drive. Driving was evaluated on the basis of on-road testing (for licensed drivers) or an off-road track. As such, relationships between patients' performance on cognitive tests and their actual on-road driving ability were unclear.

Mazer et al., (1998) assessed the driving and cognitive test performance of 84 stroke patients on average 4.5 months after stroke. Fifty-one patients failed the on-road test. Those who passed on the road did better on perceptual tests and were significantly younger than those who failed. Using logistic regression analysis, Mazer et al., (1998) combined client characteristics (such as age) with the cut off scores of the cognitive tests which best predicted road failure. The tests with the most predictive value in the logistic regression model were the Motor Free Visual Perception test and part B of the Trail Making Test. However, as with the Simms (1985) study, this was not a prospective study but a review of patients seen by one driving evaluation service. Eight patients were precluded from the on-road test on the basis of perceptual test scores deemed to be 'incompatible with driving' and regression models were generated according to side of stroke, even though no significant differences in road performance were found according to side of lesion.

Lundqvist and co-workers (2000) tested 30 patients and matched controls on a neuropsychological test battery, driving on an advanced simulator and in real traffic. They found patients performed significantly worse on cognitive and attentional processing tests and had significantly less driving skill when tested on the road. Half of the patients failed the on-road test. The authors attributed patients' poorer performance to slower processing speed underlying decreased cognitive and attentional performance.

Fattal et al., (1998) tested 18 stroke and 6 head injured patients on the road and on a cognitive test battery. Eighteen patients were considered to be mediocre, five poor and one good driver(s). None of the cognitive tests by themselves discriminated between good and bad drivers. However, by calculating the sensitivity and specificity of each cognitive test to passing or failing on the road and combining the test scores in an overall battery, they were able to predict 83% of those who failed and 94% of those who passed. Hannen et al., (1998) tested 116 brain damaged patients on neuropsychological test of attentional performance and visual processing speed, plus a comprehensive on-road evaluation. Only 58% of patients passed on the road. Using discriminant analysis, they were able correctly to predict road performance on the basis of cognitive test cut-off scores plus other subject related data in 73% of cases. In view of their failure to predict reliably, they recommended routine road testing for all patients.

It is possible that language disorders may also affect the stroke patients' fitness to drive, although there has been little research to support this. Bardach (1971) noted perceptual deficits were more disabling than language deficits when attempting to train stroke patients for driving. Golper et al., (1980) found language tests did not discriminate between small groups (n=10) of aphasic patients who had decided to resume driving and those who had decided against. The patients' decisions' were not found to differ from those of a rehabilitation team on the basis of visual, physical and cognitive factors. However, no attempt was made to check on-road driving ability and given that stroke patients have been found unreliable at judging their own fitness to drive (Hartje et al., 1991; Heikilla et al., 1999; Lundqvist et al., 1997) the validity of this study is questioned.

Hartje et al., (1991) tested 36 aphasic and 29 non-aphasic patients on psychometric tests and driving on the road. They found impaired driving behaviour in a significantly higher proportion of aphasic patients. However non-aphasic patients were younger and in the absence of a comparative older non-aphasic group, no firm conclusions can be drawn about the differences in driving ability of the two groups. No statistically significant differences in neuropsychologic test performance were found between patients who passed or failed on the road. However, the tests were based on general intelligence and reaction times, which reviews have indicated to be unrelated to driving performance in both normal and brain damaged drivers (Lester, 1991, Simms, 1994).

Nouri et al., (1987) developed the Stroke Drivers Screening Assessment (Nouri and Lincoln, 1994), a collection of three cognitive tests found to be predictive of 'on-the-road' performance in stroke patients (see section 1.9).

1.8.1 Section summary

Typically early studies failed to make the distinction between different types of brain damage (Galski et al., 1990, 1993; Gouvier at al., 1989; Jones et al., 1983) or failed to use on-road driving as the criterion measure (Croft and Jones, 1987; Gouvier et al, 1989; Lings and Jensen, 1991; Sivak et al., 1981; Sullivan et al., 1974; Stokx and Gaillard, 1986) thereby obscuring important diagnostic differences or failing to answer the question of whether individual or combinations of cognitive tests could predict fitness to drive. More recent studies focussing on stroke patients have compared cognitive abilities to actual on-road driving (Hartje et al., 1991; Nouri et al., 1987; Nouri and Lincoln, 1993; Lundqvist et al., 2000). These have indicated specific cognitive abilities, which are important for safe driving and identified cognitive tests that can predict on-road performance. The Stroke Drivers Screening Assessment is one such test. Research has also recognised that stroke patients are not able to estimate their own driving ability. Given the lack of driving advice and evaluation stroke patients receive, it would seem important that those cognitive tests which are predictive of on-road driving ability are investigated further.

1.9 The Stroke Drivers Screening Assessment

The Stroke Drivers Screening Assessment (SDSA) (Nouri and Lincoln, 1994) is a collection of three tests of cognitive abilities found to be predictive of 'on-the-road' performance in stroke patients (Nouri et al., 1987). A detailed description of the test can be found in chapter two.

1.9.1 Development of the Stroke Drivers Screening Assessment

A survey of stroke patients in Bristol, followed up at home one year after stoke, revealed that of the 34% who were driving before their stroke, 82 (58%) had not resumed (Legh-Smith, Wade and Langton-Hewer, 1986). These were patients who were significantly more disabled. This prompted Nouri (1988, 1991) to establish similar figures for stroke patients in Nottingham. In a study to establish the natural history of stroke (Ebrahim et al., 1985), 157 patients were asked whether they were driving in the three months before the stroke. Those who were (51) were administered a questionnaire asking about their driving history, current driving status, driving habits and about the advice they had been given about driving (Nouri, 1988). Over half (28) had received no advice at all about driving and only three had undergone a medical assessment. Some (30%) had resumed driving without any medical advice. Only eight patients had informed the DVLA of their condition and only ten were aware that it was their responsibility to do so (Nouri, 1988).

Nouri et al., (1987) examined the predictive value of a cognitive test battery. Forty stroke patients (36 men, 4 women , mean age 59.2 years SD 9.9, range 33 - 75) between six weeks and four years post stroke and who were driving in the three months prior to onset, were recruited from successive admissions to Nottingham hospitals. Sixteen had suffered strokes affecting the right side of the body and 24 left. Patients were not excluded on the grounds of physical disability and only if they had a medical condition, such as epilepsy, which precluded driving (as specified by the DVLA). Visual deficits (with the exception of blindness and previously identified homonymous hemianopia) were not precluded, since there was no evidence to suggest they were unfit to drive.

Patients were assessed on a battery of cognitive tests by a research psychologist, who was unaware of the patients' medical history. Tests were selected on the basis of earlier work (Sivak et al., 1981), because they had been found useful in clinical practice (Smith, 1980), or because they were thought to assess abilities relevant to driving in brain damaged patients. They included measures of spatial ability and visual memory, such as Cube Copy (Whiting et al, 1985) and Rey Figure - copy, (Rey, 1959); Visual inattention and concentration (Dot cancellation, Grewell, 1953); Choice reaction time and hand/eye co-ordination (Four Choice Reaction Time, Wilkinson and Haughton, 1975, Pursuit Rotor Fourth Instruments); Reasoning ability (What's in the Square, What else is in the Square, E.J. Arnold); Motor sequencing (Hand sequencing, Kimura and Archibald, 1974) and Visual acuity, Stereodepth Perception and visual fields (Titmus Vision Tester and Perimeter, Clement Clarke). Tests were completed in one sitting in the same order.

This was followed by an on-road test, over a set route with a BSM instructor, experienced in the assessment and tuition of disabled drivers. The car was adapted with controls to suit the disability where required. Subjects were graded into pass, borderline and below standard. Ratings of the driving instructor were cross-checked by the researcher who sat in the back of the car during each assessment. Using the cognitive assessments as the dependant variable, the cognitive test scores were then compared between the three categories of BSM gradings in a one way ANOVA to see whether any of the cognitive tests distinguished between the groups of drivers. Nine out of the 23 tests showed significant differences between gradings. Scheffe's test for grouping means was used to identify between which groups the significant differences occurred. On each of the tests, all those who passed the road test, scored significantly better than those who were 'below standard'. In addition, for two of the tests, subjects in the borderline group performed significantly worse than those in the pass group. The analysis was repeated for the independent assessor's gradings. Again, 9/23 measures showed significant differences between those who had passed the road test and those whose driving was 'below standard'. Using the driving outcome as the dependant variable, discriminant function analysis was used to see which combination of test scores would provide the most accurate prediction of driving performance. As there were only four borderline subjects according to the BSM instructor, 'borderline' and 'below standard' categories were combined to form a fail group. Only 36 patients were used in the analysis as three had a missing discriminating variable (Choice reaction time) as the test was being used in another study.

The tests that contributed most to the overall prediction of driving outcome were the Dot Cancellation-false positives, Rey Figure, Pursuit Rotor, Token Test, Vision Testing, Recognition Memory Test, Cube Copying and Hazard Recognition. Using the unstandardized canonical discriminant function coefficients, the following linear equation was generated to predict suitability to drive.

(Dot Cancellation false positives x 0.14) + (Rey Figure Copy x -0.10) + (What else is in the Square x 0.09) + (Pursuit Rotor, 15 RPM x 0.05) + (Token Test x -0.12) + (Visual Acuity, near x 0.19) + (Visual field, left x 0.03) + (Recognition Memory Test, Faces x -0.19) + (Cube Copy x 0.09) + (Hazard Recognition x 0.12) -1.19

When re-applied to the same group this formula correctly classified 37/39 patients (94% accuracy). The findings were then validated on a further group of patients to see if similar results would be found or whether the findings were unique to this study. Forty stroke patients, a minimum of six weeks post stroke, all of whom were driving immediately beforehand, were tested on the same battery of cognitive tests (with the exception of the Choice Reaction Time Test, Stereodepth Perception and the Hand Sequencing test, which had been found to be of no predictive value). Patients then underwent a road test with a different instructor to that used in the previous study (because the instructor used in the earlier study was no longer employed by BSM). Again patients were rated overall as pass, borderline or fail. Data from the two studies were grouped together for analysis. Of the fourteen cognitive tests completed by both groups, 12 showed significant differences between grading categories (Nouri, 1991). Sheffe's procedure revealed that on all 12 measures, subjects in the pass group scored significantly better than those who failed on the public road. For three measures, subjects in the borderline category scored significantly better than those who failed. Although the intention was to apply the discriminant equation generated by the first group to the second group of patients, the road test results differed between the two groups, with over half of the patients in group 2 failing their road test and eight considered to be 'borderline'. Therefore, the groups were amalgamated and a random sample of 45 (21 who has passed the on road test and 24 who had failed) was taken from the 79 patients. Using the three cognitive tests that best distinguished between the groups of drivers, new discriminant equations were generated from the results, which when re-applied to the group, correctly classified 82.2% of cases. When applied to the remaining patients, 79.4% were correctly classified. The linear equations were:-

PASS (Time taken (secs) to complete the Dot Cancellation test x 0.012) + (Number of Dot Cancellation-false positive errors x 0.216) + (What else is in the Square? x 0.409) + (Road Sign Recognition x 1.168) -13.79

FAIL (Time taken (sec.) to complete the Dot Cancellation test x 0.017) + (Number of Dot Cancellation-false positive errors x 0.035) + (What else is in the Square? x 0.185) + (Road Sign Recognition x 0.813) -10.042

The equation producing the highest discriminant coefficient indicated which grading of driving performance the subject was likely to receive.

In a further study, the predictive ability of the SDSA was compared with existing assessment procedures (the advice of the GP and DVLA) to measure its effectiveness as a screening test (Nouri and Lincoln, 1993). Patients referred from three stroke units, (Mansfield, Lincoln and Nottingham) for advice on their fitness to drive, were given a road test in a dual controlled, automatic car over a set route on the public road. They were then randomly allocated to two groups. One (n=27) was tested on the SDSA and scores were used to predict the likelihood of passing a road test. Results were passed to the patient's GP with a recommendation about fitness to drive. The control group, who were not tested on the SDSA, were told to ask their GP's advice regarding their fitness to drive. Six months later, patients were contacted to ascertain the decisions on fitness to drive. The two types of procedure (cognitive Vs standard) were compared to see which agreed most closely with the driving test outcome.

The SDSA correctly predicted the road performance of 81% of patients. Whereas the performance of 56% was correctly predicted in the control group (where the decision was made by either the GP or the DVLA). The likelihood ratio (95% confidence interval) of the findings having occurred by chance indicate that the SDSA predicted road performance significantly better but when left to the GP or the DVLA, the decision was no better than chance (Nouri and Lincoln, 1993).

1.9.2 Limitations of the SDSA

Due to discrepancies in the literature about the subject to variable ratio needed for detailed analytical procedures such as discriminant analysis (Tabachnick and Fiddell, 1996, Stevens, 1992) it could be argued that the generalizability of Nouri and co-workers (1987) findings is weakened by the sample size. However, at the time, this study was the largest study of stroke drivers in Europe and one of the few to use public road testing as the criterion measure to validate cognitive test results. Given the length of time taken to recruit stroke patients who were previously drivers and to conduct studies of this kind, it was not feasible to further validate the test on a much larger group of patients. This now needs to be done to generate stroke driver norms, which would facilitate test interpretation and improve reliability.

Inspite of their predictive validity for driving, two of the SDSA subtests, were not previously standardised neuropsychological tests. The Square Matrices was adapted from a children's game 'What's in the Square' (E.J. Arnold) thought to involve reasoning abilities and the Road Sign Recognition test was developed as a measure of visual perception related to driving as no others existed. Therefore, it remains unknown which cognitive abilities these two subtests actually measure. Further validation of these two subtests is required.

1.9.3 Section summary

The Stroke Drivers Screening Assessment (SDSA) was developed in Nottingham to address the question of 'fitness to drive' in stroke patients. Designed as a simple measure of cognitive abilities for driving after stroke (Nouri et al., 1987), it takes less than 25 minutes to administer, has good face validity and is predictive of driving in stroke patients with 80% accuracy (Nouri et al., 1987; Nouri and Lincoln, 1993). The purpose of the SDSA was to introduce some form of cognitive assessment where existing procedures meant none took place. However, two of the SDSA subtests were developed for the SDSA, therefore it is not known which cognitive abilities they assess. A further study was needed to determine what is measured by the SDSA Square Matrices and Road Sign Recognition tests i.e. to determine their concurrent validity.

1.10 Definition of Validity

Validity is concerned with the degree of confidence that can be placed on inferences drawn from a test's results i.e. ensuring that it measures what it is believed to measure so that valid conclusions can be drawn from the results. There are two reasons for checking validity, firstly the nature of what is being measured (for example, the consequences of misdiagnosing a life threatening disease or putting an unsafe driver on the road) and secondly the test's relationship to the purported cause (e.g. driving) Does it give the correct answer? Traditionally three forms of validity are considered: content validity, criterion validity and construct validity (Landy, 1986).

1.10.1 Content validity

Content validity is concerned with whether the test actually measures disorders, behaviours, attitudes or knowledge that we want to assess. In the case of the SDSA, does it measure cognitive skills that are important for driving and therefore do inferences drawn from the test relate to driving on the public road? That is can we infer that the person who performs poorly on the SDSA will also perform poorly in a real life driving situation? If the test fails to measure skills that are important for driving, then it is likely that inferences drawn from the test will be wrong. A test needs to have high content validity so that inferences drawn are valid under a variety of conditions and in different situations (Streiner and Norman, 1998).

1.10.2 Criterion validity

Criterion validity is concerned with the correlation the test has with other measures of the deficits being tested, i.e. how a person who performs at a certain level on a new test does on some criterion measure. The criterion measure is usually an accepted "Gold Standard", which in the case of the SDSA, is the public road assessment. Criterion validity can be divided into two types: concurrent and predictive validity. Concurrent validity is the correlation of the test with the criterion measure. For example the correlation between the SDSA Dot Cancellation sub test and other known measures of concentration. With predictive validity, the criterion is not usually available until some time in the future, (i.e. it will not be known whether the SDSA can predict how safe someone will be as driver until they have been tested on the public road).

1.10.3 Construct validity

A construct is a 'mini-theory' that explains the relationships among various behaviours or attitudes. Constructs arise from larger theories or clinical observations. Construct validity refers to a range of approaches used when trying to measure a hypothetical construct e.g. fitness to drive (Streiner and Norman, 1998). Construct validation is an on-going process, of learning more about a construct, making new predictions and then testing them.

1.10.4 Summary

Different types of validity require different strategies for testing. One important strategy is to check that tests are appropriate for groups other than those on which they were originally validated so that inferences made for them are as valid as the original population. This is checking the predictive validity. Another is to check that a test measures what it is believed to measure by ensuring that it correlates with other known measures of the deficits being tested i.e. concurrent validity. A third is to learn more about a hypothetical construct (in this case 'fitness to drive') by testing a new prediction about it.

Validation of the Square Matrices and Road Sign Recognition sub tests therefore requires stroke patients' performance on these tests to be checked against their performance on other known tests of the cognitive abilities thought to be measured by these two sub tests. This will determine the concurrent validity of the SDSA. Then, by testing patients with acquired neurological disabilities other than stroke on the SDSA and on the public road, the predictive validity of the SDSA for these groups of patients will be determined. Finally, the assumption that the public road test is the 'Gold Standard' of driving ability will be checked by testing the null hypotheses that ratings made by two driving instructors will differ when testing the same patient on the road at the same time. This will determine the construct validity of the public road assessment (gold standard of driving).

1.11 Driving in People with Traumatic Brain Injury

1.11.1 Traumatic Brain Injury (TBI)

TBI is defined as 'brain injury caused by trauma to the head including the effects of direct complications of trauma, notably hypoxaemia, hypertension, intracranial haemorrhage and raised intracranial pressure' (Barnes et al.,1998). The incidence of TBI in the UK is approximately 300 per 100,000 but this may be an underestimation for socially deprived urban areas (Tennant, 1995, Torner and Schootman, 1996). Seventy percent of all head injuries occur in people under 30 with the majority amongst young men aged between 15 and 25 - the group most at risk from Road Traffic Accidents (RTAs) (Vogenthaler, 1987). RTAs account for as many as 40 percent of injuries and the most severe injuries. Young children and elderly people also have high rates (sometimes as much as four times the national incidence rate) but exact figures are difficult to identify since the NHS does not keep complete and accurate records (Barnes et al., 1998).

Severe TBI, defined as an injury causing unconsciousness for more than six hours and a Glasgow Coma Score (GCS) (a measure of the presence, degree and duration of coma) after initial resuscitation of three to eight, affects approximately eight in 100,000 in the UK each year, with the incidence of moderate injury (unconscious for more than 15 minutes and a GCS after initial resuscitation of 9-12 (Barnes et al., 1998)), being approximately 18/1000,000 and the rest (250-300/1000,000) mild (Barnes et al.,1998).

Approximately 90% of patients undergoing neuro-surgery make a good physical recovery (in that they are independently mobile one year post onset). Of those who do not and among those with severe injury, there is an increased likelihood of neurological deficits that may include spasticity, in co-ordination, rigidity, slowness and poor motor initiation, fatigue, reduced drive and involuntary movements. Some patients may also exhibit disturbance of balance and persisting tremor.

Traumatic injury to the brain, whether 'closed' where damage results from blunt impact (Richardson, 1990) such as the skull hitting the car windscreen or penetrating, where the skull is pierced by a sharp object or propelled missile, produce both primary and secondary damage. At the moment of impact neurones throughout the brain tear, causing diffuse axonal injury. This results in haematoma, swelling and ischaemia causing widespread structural damage.

TBI gives rise to physical, behavioural and cognitive deficits. Cognitive and behavioural deficits are particularly important, since they result in the greatest morbidity and impact most upon independence in daily life. The ability to return to work (Annoni et al., 1992; Olver et al., 1996; Van Zomeren and Van den Burg, 1985) and maintain social activities are greatly impaired (Mazaux et al., 1997).

TBI patients with closed head injury tend to show patterns of symptoms, rather than loss of particular cognitive abilities. These differ in severity and persistence depending on the extent of damage and the patient's pre-morbid character. They tend to be impairments of memory, attention, concentration and mental slowing, fatigue, (Brouwer at al., 1989; Van Zomeren and Van den Berg, 1985) heightened distractibility and difficulty doing more than one thing at a time (Lezak, 1995). In particular, memory, especially new learning has been described as the 'hallmark of head injury' (McKinlay and Gray, 1992), with notable problems in the acquisition and retrieval of information (Lezak, 1995).

1.11.1.1 Attention

Although not present in all cases, attentional deficits are common, especially in people whose injuries occur during rapid deceleration (Brouwer et al., 1989; Van Zomeren and Brouwer, 1992). Behavioural slowing of mental processing and response are characteristic features of TBI with slowed information processing response reflected more by the complexity of tasks, rather than their motor complexity (Ponsford and Kinsella, 1992; Tromp and Mulder, 1991).

1.11.1.2 Executive Dysfunction

Executive functions refer to a core group of cognitive processes that involve planning and problem solving, abstract thinking, verbal fluency, self control and the regulation of behaviour, self determination and awareness of oneself and one's surroundings (Crosson et al., 1989; Lezak, 1978; Stuss 1991). Executive functions are also concerned with the expression of cognitive ability rather than the ability itself (Lezak, 1995) i.e. patients have the capacity to perform but lack initiative to do so unless cued. The greater the damage to these abilities, the more socially dependant and dysfunctional patients become (Lezak, 1995) and the greater the accountability for poor outcome in those with severe damage.

Those with frontal and right cerebral hemisphere injuries lack awareness of their deficits (Allen and Ruff, 1990; Crosson et al., 1989) and their mistakes. As a result they lack motivation and the ability to monitor their own performance. It is not unusual for patients with cognitive and motor deficits to voice their intentions to return to work or embark on new projects, however unrealistically. Typically they underestimate problems in emotional control and social interaction (Prigatano et al., 1990) and are more likely to show impaired reasoning and verbal fluency (Brooks et al, 1986; Ellis and Zahn, 1985). Injury to the frontal lobes are often most handicapping as they interfere with the patients ability to use knowledge and skills fluently, appropriately or adaptively (Lezak, 1995), abilities deemed important for driving (Engum et al., 1988; Brouwer and Withaar, 1997).

1.11.1.3 Measures of severity classification and outcome prediction.

The Glasgow Coma Score (GCS) (Teasdale and Jennett, 1974) after initial resuscitation is accepted as a more reliable severity indicator for clinical purposes than length of coma or Post Traumatic Amnesia (PTA) (Barnes et al., 1998). However, exceptional cases may be misclassified when the scale is used in the first hours or day post trauma as intended (Richardson, 1990), such as those who have delayed traumatic intracerebral haematoma but no initial loss of consciousness.

PTA is defined as the number of days elapsing between injury and the re-instatement of continuous day to day memory, as demonstrated by recall of specific items of information not of immediate relevance to the subject, that had formally been presented to the subject on the previous day (Barnes et al., 1998). Although estimates of severity based on PTA generally agree with the GCS severity range, differences occur in the finer scaling at the extremes (Biggler, 1990). The main difficulties in using the PTA as a severity indicator are concerned with determining the actual duration of PTA.

1.11.1.4 Outcome

Deficits resulting from severe TBI tend to improve steadily in the first three to five years after injury and then more slowly for as long as 15 years (Barnes et al., 1998). Later improvement may result from learned accommodations and compensations rather than functional recovery per se (Lezak 1995). Studies of TBI patients followed up several years after injury indicate many patients fail to make a complete recovery (Brooks et al. 1986; Brouwer at al., 1989; Van Zomeren and Van den Berg, 1985). This is largely due to the residual cognitive and behavioural deficits that prevent patients from resuming former activities and social relationships.

A return to driving for many is an important step in normal re-integration in society and anecdotal evidence suggests it is often viewed as a pinnacle of the rehabilitation process, rather than a means of transport. Regarded as a right rather than a privilege, the importance of driving is often overemphasised in the goal to achieve a normal independent lifestyle. Mazeux and colleagues (1997) looked at long term neuropsychological outcome and loss of autonomy after TBI. They found that not driving was one of the most disabling social skills. The complexity of the driving task, pre-empts concern over whether the residual deficits of TBI patients may jeopardise fitness to drive.

1.11.2 Predicting fitness to drive in traumatic brain injured patients

Little is known about the driving abilities of patients with TBI. Whilst they may not be a high risk group for recorded accidents (Van Zomeren et al., 1987), they may display risky behaviours and poor driving skills (Korteling and Kaptein, 1996). There is evidence to suggest that many people with TBI resume driving without complications (Brouwer et al., 1990) but this does not necessarily mean they are safe drivers.

On the other hand, based on little evidence, a large proportion of patients may be unfairly precluded from driving. In the United States, the re-licensing rate of TBI patients is significantly lower than that of patients with physical disabilities. Shore et al., (1980) report a success rate of 72% for physically disabled drivers and only 50% for cognitively impaired drivers. This is possibly done on the basis of "pre-driver" or off-road evaluations, which include cognitive and simulator assessments but rarely on-road testing.

There have been several attempts to predict fitness to drive in people with TBI. Van Zomeren and colleagues (1988) followed up nine severe TBI patients, six years after injury. They were compared to controls on a neuropsychological assessment battery, a thorough neurological examination and two measures of driving ability; a test of lateral position control (the ability to steer a vehicle on a straight course), followed by an on-road test in their own car with an advanced driving instructor. This routine test of advanced driving used by the Dutch Licensing Authority was rated as satisfactory or insufficient. Brain injured patients performed worse on both measures of driving ability but there was no statistically significant difference between the two groups in the number of errors on the on-road test. There were, however, differences in the qualitative ratings. Five brain damaged patients (but no controls) were rated as insufficient. The TBI patients were also impaired on the cognitive tests, yet this was unrelated to driving skill, which the authors suggest can be explained by compensatory mechanisms in the driving task. Although this study illustrates that TBI patients can be safe drivers several years after injury, it doesn't support the predictive value of cognitive tests. The fact that subjects were driving in the time between injury and the study suggests they have learned to compensate for their cognitive deficits by alterations in driving behaviour. It could also be argued that a global rating of driving performance is more important than error ratings, since individual errors say little about when or where the error occurred, or the potential for danger arising from it, whereas global ratings account for these factors.

Gouvier et al., (1989) found TBI patients performed consistently worse than able bodied and spinal cord injured patients when compared on a battery of psychometric tests and an in car driving tests. Eight driving manoeuvres were rated as pass, marginal or fail both by a driver evaluator sitting in the car and an observer standing outside the vehicle. Using these as the criterion variable, data were analysed to identify measures, which were useful in differentiating between the groups and in predicting driving performance. A prediction accounting for 79% of the variance in driving scores was obtained. A measure of information processing capability (The Oral Digit Symbol Modalities test) was by far the best predictor and alone accounted for 70% of the variance in the driving score, although performance related tests were also included in the prediction. Unfortunately, the high measurement reliability achieved by restricting the in-car test to a set course with set manoeuvres is likely to be reduced when more realistic performance criterion, such as public road tests are used. The applicability of Gouvier's findings is limited by the small sample size and the closed course nature of the driving test. Although the findings yielded useful information about which cognitive tests can distinguish between groups of able bodied and TBI patients, in the light of more recent research (Brouwer and Withaar 1997; Korteling and Kaptein 1996; Van Zomeren et al., 1988), it is likely that the predictive validity of these tests is restricted to driving on the operational level (basic car handling skills) rather than higher levels of driving (tactical and strategic) which can potentially be measured on a public road test. Of interest however, is that the closed course test did not distinguish between TBI and able bodied subjects, suggesting that it measures only the physical capability to drive and does not test higher order cognitive functions, such as executive abilities or divided attention. Given both the unpredictable nature of brain injury and the complexity of the driving task it would seem ironic to reduce driving to a level where important cognitive abilities are potentially overlooked. Such tests are now only thought to measure basic car handling (operational level) skills, rather than higher levels (tactical and strategic) of driving, which may be more pertinent in brain damaged people (Brouwer and Withaar 1997, Korteling and Kaptein 1996, van Zomeren et al., 1987).

Priddy et al., (1990) surveyed 50 TBI drivers, six months or more post discharge, 21 of them had a valid driving licence, only 19 were driving. They found tests of perceptual deficits (Benton Visual Retention Test and Judgement of Line Orientation) differed significantly between licensed and unlicensed participants (suggesting better perceptual abilities among drivers) but that measures of severity and intelligence did not. Later, Brooke et al., (1992) compared 13 closed head injury patients to a control group using standardised measures of cognitive function and driving performance. Both the cognitive and driving tests were carried out by examiners blinded to subjects' medical condition and group membership. The researchers found only a modest significant correlation (r = 0.44) between the sum of scores on the tactual performance test (a test of the ability to plan and manipulate visual and tactual information about objects in two or three dimensions and of sustained attention and flexibility) and the Trail Making Test and the overall pass/fail rating of driving ability. Rather than compare each cognitive test measure to driving outcome, they combined the scores into indexes, which they considered sensitive to deficits in the cognitive skills needed for driving. Five out of the thirteen TBI patients failed the driving test. The difference between WAIS-R Verbal and Performance IQ and between

Block Design and other performance tests of the WAIS were not related to passing or failing on the road. Interestingly, post hoc analysis showed no significant correlations between standardised measures of cognitive function and driving outcome.

In this study, as in that by Gouvier et al., (1989) the driving test was rigidly standardised, possibly bearing little relation to real-life driving. Patients were instructed to follow a standardised course, which was given both a quantified score (based on set manoeuvres) and a global rating. Although the score was significantly related to the global rating ($r = 0.58$), they were not identical. The fact that the additional cognitive assessments related to neither outcome suggests either that they do not test the skills needed for driving over a directed course (again operational level driving) or that they simply do not test the skills required for driving. The very modest relationship between tactual performance test and driving ability suggests that either the cognitive tests or the measure of driving ability used were insufficiently sensitive. However, any firm conclusions are spurious given the small sample. Some individual performance scores fell within those of the control group, which the authors suggest highlights the need to recognise individual differences. Brooke et al. (1992) concluded that cognitive tests alone are insufficient to provide a valid basis for making decisions but that they reveal deficits and thus highlight potential driving problems.

Korteling and Kaptein (1996) tested 38 TBI patients on tests of information processing ability, time estimation, tracking reaction and perceptual speed plus an on-road test. They found perceptual speed and time estimation were significantly correlated with driving performance. However, when combined with driving experience and coma duration, they could only explain 35% of the variance in the on-road test. They concluded that more driving related simulation tests needed to be developed and because of the sheer complexity of the driving task, assessments need to consider higher level strategies such as risk taking behaviour.

1.11.2.1 Individual differences.

Variability in individual performance is a recurrent theme across studies. Predicting driving ability among head injured patients has been found particularly difficult especially for patients who score in the borderline range on cognitive tests (Brooke et al., 1992; Brouwer and Withaar, 1997; Lambert and Engum 1992). Unfortunately many TBI patients fall into this category and as a result up to 20% of cases may be misclassified (Simms, 1985; Simms and O'Toole, 1994).

Fisk et al, (1998) surveyed 384 TBI patients of whom 83 responded an average 3.3 years after injury. Sixty percent were currently active drivers, most (>60%) drove every day and more than 50 miles per week. Most (63%) had received no driving evaluation. Given the low proportion of drivers responding, it is likely that results are biased in favour of 'good' drivers (i.e. those who believed they shouldn't be driving, failed to respond). The lack of evaluation however, is common (Pidikiti and Novack, 1991; Fisk et al., 1997).

It is not exactly known how frequently or how far TBI drivers drive in an average week, although driving exposure is known to be an important crash risk factor (Haselkorn et al., 1998). It is also unclear what advice or evaluation TBI patients receive regarding fitness to drive. Advice and assessment appears to depend more on geography, access to rehabilitation services and the experience and preferences of driving evaluators than standard procedure or empirical evidence. Therefore, this suggests the need for further evaluation of cognitive deficits in relation to on-road driving performance.

1.12 Driving in People with Multiple Sclerosis

1.12.1 Multiple Sclerosis

Multiple sclerosis (MS) is a deteriorating neurological condition characterised by progressively developing neurological symptoms and behavioural change. It typically affects young to middle aged adults, the average age of onset being 30 years. The most prominent symptoms are losing control of a limb, dysarthria, eye muscle imbalance (causing double vision, transient blindness in one or both eyes), loss of spincter control and patchy sensory changes (e.g. numbness) and fatigue (Lezak, 1995). The condition affects approximately 85,000 people in the UK and is more common in women than men (3:2) (MS Society, 1999).

Symptoms are caused by "patchy" destruction of the myelin sheath (a fatty layer of insulation around nerve fibres) which affects the way nerve impulses are transmitted. Sclerotic plaques then form at the demyelination sites (McFarlin and McFarland, 1982; Raine, 1990b; Rao 1986). The nerves and axons themselves remain largely unharmed. Plaques commonly form around the cerebral ventricles, but no part of the central nervous system is exempt. In most (90%) cases, plaques can be detected using magnetic resonance imaging (Paty and Li, 1988; Rao 1990b; Whitaker and Beneviste, 1990; Willoughby and Paty, 1990; Goodkin et al., 1994). However, other confirmatory clinical tests are also needed (Poser, 1994).

Although random, demyelination especially affects optic nerve fibres, nerve chiasm and tract and those in the brain stem and spinal cord. However, the long myelinated fibres of the leg muscles also have a high rate of involvement (Reder and Anetel, 1983). The disease progresses at different rates in different people. The terms 'late' and 'early' describe stages of the disease but refer to severity rather than time since onset.

There are four distinct patterns in the disease process. Most people start with the Relapse-Remitting form of MS, which presents early on with sensory, usually visual, symptoms. Patients have unpredictable attacks (relapses), which may last a few hours to several months, varying in severity. During relapses, new or previous symptoms occur and patients may need hospitalisation. These are followed by remissions, which can often last years, where there are fewer or no symptoms. In some, this changes to a more rapid Secondary Progressive type, which affects around 40% of sufferers. Only about 15% have chronic Primary Progression type (in whom there is more cognitive deterioration) from the outset. This is characterised by a steady worsening of symptoms, which either level off or continue. Benign MS, which affects around 20% of patients, is characterised by a few mild attacks followed by complete recovery. Symptoms are predominantly sensory.

1.12.2 MS and cognition

Cognitive dysfunction is thought to be present in between 30 - 70% of cases (Heaton et al., 1990; Huber et al., 1987; Lyon-Caen et al 1990; Rao 1990b), although 40% of those with only mild neurological symptoms, may show no cognitive impairment (Monti, 1981). In some patients, the cognitive and physical deterioration run alongside each other but there is nothing predictable about the nature of cognitive decline. It may be unrelated to disease duration or disability (Rao et al., 1991). People with MS tend to experience cognitive deficits, which can be explained by patterns of lesions in cerebral white matter and the periventricular areas (Lezak, 1995). Their random occurrence and the variability in disease progression mean some patients function normally whilst others deteriorate rapidly or have fluctuating mental ability (Lezak, 1995). The most frequently observed changes are those in memory and learning, attention, information processing and executive functions (planning, sequencing, problem solving and self monitoring) (Brassington and Marsh, 1998).

1.12.2.1 Memory and learning

Evidence of memory impairment is found in between 40 - 60% of patients (Rao et al., 1993). However, there is no distinctive pattern in disturbance and it has been related to impairment of other cognitive functions (Minden et al., 1990). Learning and short term memory are intact in the early stages, although interference affects short term memory for some (but not all) patients (Coolidge et al., 1996). Retrieval of information is a common problem amongst MS sufferers, affecting both verbal and visual memory systems (Rao et al., 1993; Coolidge et al., 1996). Even those, who in clinical settings appear to have intact abilities for short term storage, fail to register a lot of the ambient information others pick up effortlessly in real life situations (Lezak, 1995). It is this slowed processing speed that is attributed to poor memory. Slowed processing, which reduces the amount of information that can be attended to, processed and registered at any time is thought to contribute significantly to verbal memory impairments (Litvan et al., 1988; Rao et al., 1989). Memory complaints, however, are poor indicators of memory dysfunction (Fischer, 1989) since attentional deficits also contribute significantly to memory disorders (Litvan et al., 1988; Beatty et al., 1996).

1.12.2.2 Attention

MS patients tend to exhibit both visual and auditory attention deficits (Ron et al., 1991; Rao et al., 1991), particularly on complex tests such as the Paced Auditory Serial Addition Task (Litvan et al., 1988). Slowed motor speed is thought to account for poorer scores on some measures of attention, hence the suggestion that better estimates of attentional ability are obtained by measures relying on verbal responses (Beatty and Scott, 1993).

1.12.2.3 Information processing

MS patients may display reduced information processing speed independently of motor impairment or lower global cognitive functioning (Rao et al., 1989; Brassington and Marsh, 1998). This has been attributed to slowed memory scanning, influenced by illness duration (Rao et al., 1989). Information processing impairment is thought to affect both auditory and visual domains equally (Diamond et al., 1997).

1.12.2.4 Executive functions

Many patients perform at normal levels on reasoning tasks but perform worse with a chronic progressive type course and possibly with disease duration (Lezak, 1995). Problem solving difficulties are thought to reflect impaired concept formation rather than perservation (Beatty et al., 1996) and it is not known whether or not they are attributable to frontal lobe damage. MS patients have been found to perform worse than controls on tests of abstract reasoning (Beatty et al., 1995) and sequencing ability (which was unrelated to motor sequencing) Beatty and Monson (1994). Cognitive inflexibility is also a common feature of

MS patients (Brassington and Marsh, 1988), in particular among those with the chronic progressive form (Mahler, 1992). It has been suggested that deficits in executive functioning may result from impaired information processing ability (Beatty, 1993).

1.12.3 Predicting fitness to drive in people with MS

The prevalence of MS in people of driving age in the community and the incidence and nature of cognitive impairment among sufferers would indicate the need for research into driving ability, yet few studies of MS drivers have been reported. Shanke and co-workers (1995) examined 33 MS patients (20 women and 13 men, mean age 43) medically and neuropsychologically for their fitness to drive. In addition some were given a practical driving test. On this basis, 19 patients were considered fit and 14 unfit to drive. Regression analysis revealed cognitive and emotional deficits to be more important than illness duration or severity in the decision of fitness to drive. A measure of visuoconstructive capabilities best distinguished between safe and unsafe drivers.

In an investigation of the contribution of visual and cognitive factors in the prediction of driving ability, Simms and O'Toole (1994) included 39 MS patients in their follow up (see earlier), one year after undergoing medical, visual, cognitive, physical and in-car testing as part of the routine assessment of fitness to drive at the Banstead Mobility Centre. Completed road test results were only available for 16 patients with MS (one of whom was considered unsafe). On this basis, they found that MS drivers were more likely to show impairment in specific areas, rather than perform badly overall. In particular, they were poor at using mirrors, road scanning and road positioning but competent in controlling the car when turning or using indicators. Attempts to establish driving status at one year, were hampered by poor response rate. Of the 39 MS patients in the study, only 15 replied and only one person admitted to an accident. When cognitive test scores were used to identify drivers considered to be good, adequate or poor on the basis of the on-road test, no significant differences were found between good and adequate drivers. Of the 15 tests administered, only the Token Test (a test of verbal comprehension and immediate span of attention) and the Tapping Test (which measures frontal functioning) distinguished good and adequate drivers from poor ones. The researchers then combined cognitive tests with clinical data (see earlier, 1.1.5) to predict on-road tests and driving status at one year, with 80% and 100% accuracy, respectively.

In 1977, Knecht, using statistical traffic offences and accident records from the University of Zurich's Institute for Forensic Medicine, compared the driving records of 35 MS patients to controls. He found that MS patients caused significantly more offences than controls and concluded that special care and restraint was necessary in issuing licences to patients with multiple sclerosis. He advocated regular medical check ups if patients were to be allowed to keep their licences. Given the limited information about the driving ability of MS patients, further investigation is needed.

1.13 Driving in people with Parkinson's disease

1.13.1 Parkinson's Disease

Parkinson's disease (PD) is a progressive neurological disorder affecting learned voluntary movements including walking, talking, writing and swallowing

(Parkinson's Disease Society of the UK, 1999). There are more than 120,000 people with PD in the UK. It was first described by Dr James Parkinson in his essay "The Shaking Palsy" published in 1817 and was subsequently named after him. The symptoms of Parkinson's disease result from the loss of the chemical messenger dopamine (in the brain), due to severe degeneration of the substantia nigra. There are three predominant symptoms; tremor, muscular rigidity and bradykinesia (slowness of movement). Other symptoms include difficulty initiating movement (akinesia), dysarthric speech and general loss of agility and fine co-ordination (Lezak, 1995). Other characteristic features are, the expressionless, unblinking 'masked facies' and shuffling gait, difficulty initiating walking and stopping once started (Lezak, 1995). Although sensory reception remains intact, most PD patients have a defective sense of smell (Doty et al., 1988) and up to a third experience pain, numbness, cold or burning sensations (Bannister, 1992; Koller, 1984; 1991; Nutt et al., 1992). Not all patients present with all symptoms, particularly in the early stages of the disease.

Cognitive deterioration affects almost all PD sufferers to some extent, ranging from subtle changes to very severe impairment (Granerus, 1990; Sullivan et al, 1989). It takes place slowly, with different functions deteriorating at different rates (Tweedy et al, 1982). Impairments tend to be greater the more severe the motor symptoms (especially bradykinesia). The cognitive changes in PD are similar to those occurring with frontal lobe damage. Patients tend to show difficulty in switching or maintaining a set, initiating responses, serial and temporal ordering, executive planning and in cognitive slowing and diminished productivity (Lezak, 1995).

1.13.1.1 Attention

Attentional deficits are common and show up most usually on complex tasks requiring shifting or sustained attention (Cummings, 1986; Stern et al., 1987; Wright et al., 1990) or on mental tracking tasks (Huber and Shuttleworth, 1990). Although PD patients show typical patterns of changes, as with TBI there is within group variability, so whilst group means fall well below age norms or control scores, there tend to be large standard deviations (Huber, et al., 1986; Stern et al., 1987).

1.13.1.2 Memory and learning

Patients with PD tend to have intact orientation and short term memory but impaired verbal memory, which shows up on recall tasks such as list learning or story recall and impaired visual memory when it requires a motor response (Pillon et al., 1986).

It has been suggested that two types of dementia can occur with PD, one a subcortical dementia and another more severe dementia, characteristic of Alzheimer's disease that affects more people with PD than the general population (Boller et al., 1980; Chui and Perlmutter, 1992). However, estimates of dementia (ranging from 10 to 40%) are thought to include the more severe cases of progressive cognitive decline and dementia may not be a separate condition amongst sufferers (Lezak, 1995).

1.13.1.3 Verbal functions

Word finding and retrieval difficulties are common amongst PD patients (Beatty, 1992), resulting in poor performance on fluency tasks. Other impaired verbal functions include writing problems (typically writing becomes jerky and smaller and smaller as writing proceeds - micrographia) and speech (hypokinetic dysarthria, an impairment of the mechanical aspects of speech thought to arise from rigidity).

1.13.1.4 Visuospatial functions

Frequently described visuospatial impairments include deficits in perceptual judgements, angular orientation, drawing, copying and visuoconstruction tasks (Lezak, 1995). However, some dispute this and attribute the impairments to executive function (Ogden et al., 1990; Raskin et al., 1992). The lack of consensus is probably attributable to problems in differentiating between Parkinson's disease and other syndromes, such as Lewy Body dementia, where patients present with the clinical features of Parkinson's disease but among whom the incidence of visuospatial and frontal lobe deficits is higher (Ince et al., 1998).

1.13.1.5 Mental processing speed

Motor slowing is a common symptom and affects performances on all timed cognitive tests. Mental slowing in excess of motor slowing has been shown to affect the behaviour of many patients (Cummings, 1986) and is exacerbated by task complexity (Agid et al., 1987; Cummings, 1986). Patients with normal reaction times may be abnormally slow on choice reaction time tests (Cummings, 1986). Mental slowing is also associated with depression, reported in 50-70% of sufferers (Cummings, 1986) and especially among the severely cognitively impaired (Mayeux et al, 1981; 1983).

1.13.1.6 Executive functions

Performance on tests of reasoning and judgement suggest these abilities remain intact and that patients have a realistic impression of their condition and limitations (Brown et al., 1989). However, despite normal performance on tests of comprehension of complex ideational material, PD patients consistently fail executive function tests. This has been attributed to difficulty in formulating a strategy, rather than performance per se (Saint-Cyr and Taylor, 1992) and failure to initiate changes they perceive to be needed (Ogden et al., 1990). People with PD also have difficulty coping with newness and change (Taylor and Saint-Cyr, 1992). This is thought to be attributable to central programming impairments, which affect the ability to regulate behaviour.

It is these changes which give rise to concern about fitness to drive amongst people with PD.

1.13.1.7 Treatment

The main treatment for PD is the use of Levodopa (L-dopa) to replace dopamine depletion. L-dopa can restore movement to impaired patients and improve cognitive status but not slowed cognitive processes (Pillon et al., 1989). One complication of long term L-dopa therapy, are the fluctuations in symptoms, known as the "on-off" phenomenon, related to time of dosage (Gancher, 1997; Nutt et al., 1992). Patients perform better cognitively and are more alert during "on" periods (Marsden et al., 1984). Other side effects include hallucinations, paranoid delusions, vivid dreams and confusional states (Conn, 1989) and abnormal involuntary movements (Nutt et al, 1992). Unfortunately the benefits of L-Dopa therapy begin to diminish after only 2-3 years (Agid et al. 1987); new combinations of therapies and regular reviews of dosage and timing are essential in controlling symptoms.

1.13.2 Predicting ability to drive in people with Parkinson's disease

Cognitive factors are an important component of PD and may affect driving safety, yet only one study has been identified of the relation between cognitive abilities in PD and on road performance. Heikkila et al., (1998) assessed 20 people with PD and 20 healthy age-matched controls on cognitive and psychomotor laboratory tests and on road driving. All patients were assessed by a neurologist, neuropsychologist and driving instructor and were also asked to rate their own driving ability. People with PD performed worse both on psychomotor tests and on the road. There was a high correlation between laboratory tests and driving in both groups. No relationship was found between disease severity and driving outcome. The neurologist tended to underestimate patients' driving ability. Patients were unable to estimate their own driving ability. Tests of visual processing speed, perception and speed of visual recall accounted for 62% of the variation in driving faults.

Earlier attempts to predict driving safety focussed on physical factors or accident history.

Madeley et al., (1990) examined the effects of PD on driving ability as assessed by a computerised driving simulator. Comparing ten patients with ten healthy controls, they found that both simulated reaction time and accuracy of steering were impaired in the PD group. They also found that impairment on measures of reaction time and accuracy were related to PD severity as measured by Webster's rating scale (Webster, 1968). They suggested this may be a useful measure of fitness to drive. Lings and Dupont (1992) also studied simulated driving. They tested 28 patients with PD and 109 healthy controls in a mock car. PD patients made serious errors, particularly directional errors and sometimes completely failed to react to stimuli, irrespective of the degree of severity as measured by the Webster's scale. Given the contradiction in findings to those of Madeley, they suggested the Unified Parkinson's Disease Rating Scale (Lang and Fahn, 1989) as an alternative to Webster's scale.

Dubinsky et al., (1991) attempted to determine whether PD sufferers differed from people without disabilities in terms of their driving habits and previous accidents (see earlier, 1.2). They interviewed 150 people with PD and compared them to 100 healthy controls. They found that people with more advanced disease had more accidents than those in earlier stages and importantly those with cognitive impairment had more accidents than those without, irrespective of disease severity. However, as with other acquired neurological disabilities, the association between disease severity and accident rates was not so close that severity alone could be used as an indicator of fitness to drive (Heikkila et al., 1998; Shanke et al., 1995).

On the whole, people with PD are considered to be conscientious (Ritter and Steinberg, 1979) and more likely to relinquish a licence before their own safety or that of other road users is compromised. In Dubinsky's study (1991) 21% of PD drivers had stopped because of concerns over their own safety. McLay (1989) also found that most of the drivers surveyed had given up driving.

In most cases, the process of self-declaration and subsequent inquiry by the DVLA, together with existing methods of assessment are probably sufficient. In a trial, cross checking the responses of 2000 patients with 'self declaring' medical conditions with those of the General Practitioner, only 1% made mistakes (DVLA personal communication, 1997). However, concern exists about those individuals who lose insight into their own ability to drive safely, since it is they who may fail to declare.

1.13.2.1 Section summary

Research suggests that people with Parkinson's disease tend to drive well and that disease severity may have no bearing on fitness to drive. However, cognitive impairment may be an important predictor of driving safety. Few studies have related these factors to actual on-road driving. There is also conflicting evidence concerning the usefulness of driving simulators. Further research is needed to determine which cognitive abilities are important for safe driving and at what point the driver with PD becomes unsafe.

1.14 Driving in People with Dementia

1.14.1 Dementia

Dementia is a clinical syndrome of impaired memory with at least one other change in cognition, judgement or personality, severe enough to interfere with work or social activities (American Psychiatric Association, 1987). Early signs of dementia include decline in the ability to perform complex activities of daily life such as preparing a complicated meal or driving a car.

Alzheimer's disease (AD) is the most common cause of dementia accounting for more than a half of all cases (55%). The estimated prevalence being 11.6% of people over the age of 65 and 47.8% of those aged over 85 (Evans et al., 1989). Other causes include vascular dementia (multi-infarct dementia) (20%), Lewy body disease (also a feature of Parkinson's disease) (15%), frontal lobe dementia and Pick's disease (5%) and less commonly, Cretzfeldt Jacob Disease, Down's syndrome and HIV (5%).

Dementia affects 1 in 1,000 people under the age of 65, 1 in 50 of those aged 65-70, 1 in 20 aged 70-80 and 1 in five people over 80 years old (Alzheimer's disease Society, 2000). An estimated 700,000 people in the UK are affected by dementia of one sort or another. The disease is characterised by progressive degenerative nerve cell changes within the cerebral hemispheres, resulting in progressive global deterioration in intellect and personality (Lezak, 1995).

Diagnosis alone is not an adequate predictor of function. The rate of illness progression and the cognitive strengths and weaknesses of patients with dementia are heterogeneous (Odenheimer, 1993). Patients with dementia tend to share behavioural features. These include psychosocial regression, disorders of attention, poor concentration, loss of mental tracking ability, distractibility, apathy, impaired ability to initiate, plan and carry out complex activities and essentially, disorders of memory. In addition visuospatial skills, selective attention and executive functions are affected. Coupled with this, patients lose their capacity for judgement and self care (Lezak, 1995). Most often, deficits seen in dementing disorders are not isolated but coexist in varying combinations.

1.14.1.1 Memory

Disorders of memory are the most consistent and earliest traits of Alzheimer's disease (AD) (McKhann et al., 1984). AD patients perform worse than healthy elderly controls on nearly all memory tasks (Spinnler, 1999). In particular the ability to learn new information is severely impaired. This has been attributed to attentional impairments, which interfere with encoding and storage and to an accelerated rate of forgetting (Spinnler, 1999).

1.14.1.2 Language disorders

Language disorders are characteristic of the early stages of AD (Capitani et al., 1986, 1990) and may be truly aphasic, affecting both oral and written language or restricted to discourse planning (Spinnler, 1999). Word finding during conversation and confrontation naming are often reported by relatives (Spinnler, 1999). More radical changes in verbal output become apparent in the later stages when patients are permanently in a state of mild confusion.

1.14.1.3 Visuospatial and perceptual deficits

Dressing apraxia and topographical disorientation are typical in the early stages of the disease (Spinnler, 1999). Patients tend to perform poorly on spatial perception and constructional tasks. Problems with freehand drawing are also exhibited, which are thought to be attributable to impaired lexico-semantic and visuostructural knowledge and visual attention (Grossman, 1988).

Difficulty in recognising faces is the most common early stage example of defective visuo-perceptual functioning (Mendez et al., 1990), which later progresses to difficulty in distinguishing familiar from unfamiliar faces (Spinnler, 1999). Other recognised deficits include, figure ground discrimination (common in early disease) (Della Sala et al, 1996) and object recognition (Spinnler, 1999).

1.14.1.4 Attention

AD patients tend to experience mental fatigue when attentional resources are increasingly called upon to control functions, which were once automatic. This strain, exhibited on divided attention tasks (Baddeley et al., 1997) is thought to be responsible for confusional states and short periods of aphasia and amnesia (Spinnler, 1985).

The characteristic cognitive and functional decline in people with dementia raises serious concerns for public and personal safety regarding driving. As the population ages and the incidence of dementing illnesses increases, the number of elderly drivers with cognitive impairment will increase (Kasniak, 1991). In the future demented drivers may pose a significant health problem (Odenheimer, 1993).

1.14.2 Predicting fitness to drive in people with dementia

The association between dementia and driving has been a cause for concern amongst carers and clinicians for many years but it is only more recently have attempts been made to determine how the ability to drive safely is affected by the disease process and at what point driving should cease. Although there is consensus that severely demented patients should stop driving, research has not yet determined the level of cognitive impairment associated with an unacceptable risk of injury when driving, in those with mild to moderate impairment.

In an attempt to preserve mobility and independence for as long as possible after the onset of dementing conditions such as AD, clinicians have sought methods by which fitness to drive or the risk of crashes can be determined. Some have concluded that driving privileges should be revoked once a diagnosis of AD or multi infarct dementia has been made (Freidland et al., 1988, Lucas-Blaustein et al., 1988) However, this view is strongly contested by others (Drachman 1988, Odenheimer, 1993, O'Neill, 1992).

Physicians alone are not good at saying who is and who is not fit to drive. In a study by Johansson et al., (1996) tests of visual acuity and the standard medical examination were not able to distinguish between a group of older drivers who had temporarily had their licenses suspended following involvement in crashes or other moving violations and a control group. However, cognitive test performance was related to license suspension. Subjects with suspended licenses performed less well on cube copying ($p<0.01$) and five item recall ($P<0.01$) and were more likely to have suspected or mild dementia. The authors concluded that even mild cognitive impairment contributed to the risk of losing a license because of crashes. The DVLA's advice (1998) refers to " loss of insight....and judgement" as indicators of when driving should cease but other than these vague markers, no recommendation is made for what to assess or how to assess it. Neither is it known which, if any measures designed to detect impairments that underlie these fundamental abilities, have predictive value for 'fitness to drive' in people with dementia.

The Mini Mental State Examination (MMSE), a quick measure of memory and orientation (Folstein et al., 1975), is routinely used in memory clinics and hospital services for elderly people. However, conflicting evidence exists as to its usefulness in discriminating between safe and unsafe drivers. Lucas - Blaustein et al., (1988), used the MMSE on a group of 53 patients with AD and other dementias. Using caregiver reports of crash history, they found no significant differences on MMSE scores between those who had been involved in crashes and those who had not. Freidland at al., (1988) compared the MMSE scores of 30 AD patients with 20 age-matched controls. He too found that the MMSE did not discriminate between those who had and had not crashed. On the contrary, Coyne et al., (1990) found MMSE scores to be significantly higher in drivers than those who had stopped.

Maratolli et al., (1998) found the MMSE to be predictive of adverse traffic events, findings supported by Fitten et al., (1995) and Johansson et al., (1996).

In many of these studies, results are influenced by retrospective use of the MMSE. i.e., the accidents had happened and the patient had stopped driving before MMSE testing. One drawback of the MMSE when used regularly in clinical reviews, is the potential for patients' relatives' to prompt responses while waiting to see the physician. This influence cannot be out-ruled in the studies described above. Other weaknesses of these studies include the failure to control for driving exposure, small sample size and poor generalisability (patients are specially selected groups) (Odenheimer, 1993). Therefore, while cognitive examination is recommended in determining safe from unsafe drivers with dementia, the MMSE may be insufficient for this purpose.

1.14.2.1 The risk of crashes

Patients with Alzheimer's disease are at increased risk of crashes and display faulty driving behaviours when compared to 'normal' individuals of a similar age (Hunt, 1994). In a survey of 30 families of patients with AD and 20 controls, Freidland and colleagues (1988) revealed that demented patients tended to drive until they had a crash and that crashes were 4.7 times more likely for patients than controls over a five year period.

Coyne et al. (1990) reported AD drivers have greater rates of abnormal driving events such as getting lost, having accidents, failing to obey traffic lanes, driving against traffic and making improper turns. They suggest that even mild cognitive impairment poses an increased risk for accidents. Similar findings were reported by O'Neill (1992).

Gilley et al., (1991) surveyed 333 licensed drivers with dementia to determine how long after onset they continued to drive and accident frequency in the preceding six months. The median duration of driving after onset was 28.6 months. Those with AD drove longer than those with other dementia syndromes. Of the 93 still driving at the time of the survey, 31 had had at least one form of unsafe driving incident, 15 had had accidents, 10 multiple car accidents, 10 ticketed moving violations and 5 had violated traffic laws or narrowly avoided accidents.

Efforts to measure driving ability in terms of crash history or relative crash risk in people with dementia have relied upon self and carer reports (O'Neill 1992, Lucas - Blaustein et al. 1988, Friedland et al., 1988). Such methods are subject to inaccuracy, not only because they depend on memory but because some carers have a vested interest in keeping their partner driving for as long as they can and may lack insight into the need to limit and eventually discontinue driving (Adler et al., 1999). However, in a retrospective review of state driving records for 249 people referred to a dementia clinic, Tuokko et al., (1995) found demented patients had 2.5 times the crash rate of their matched controls.

Other methods have involved the use of driving simulators. Rebok et al., (1990) tested 12 mildly demented AD patients (mean age 72.6) with a mean MMSE score of 20.8, with 18 age-matched controls (mean age 68.6, MMSE 28.9). All were still driving or had recently stopped. Patients were measured on cognitive tests and on a driving simulator (presenting driver point of view films). They were also asked to rate their own driving behaviour. They found that all AD patients rated themselves as highly capable of driving despite their high number of errors on the driving simulator. Simulators of this kind may prove to be a useful method of assessment but at present not enough is known about how driving simulator performance relates to actual driving (Kasniak, 1991).

Neuropsychological tests have been used in an attempt to find predictive measures. Kasniak and colleagues (1990) found histories of crashes and getting lost whilst driving were associated with poorer performance on the WAIS-R picture completion and digit symbol subtests and on the Weschler Memory Scale visual recall subtest.

Odenheimer et al., (1994) found significant correlations between in-traffic and closed-course driving scores for a sample of 30 drivers aged over 60. Tests of Complex reaction time, mental state (MMSE), traffic sign recognition and visual memory were significant at the 1% level and tests of frontal functioning (Trail making A) and verbal memory at the 5% level. They concluded that older drivers can be tested on the road in a systematic and reliable way when the course is long, detailed and difficult enough to elicit the problems experienced by drivers.

Johannsen et al., (1996) compared 37 older drivers with violations (crashes, speeding offences etc.) to age-matched controls and found significantly more cognitive impairment in the crash group.

Mitchell et al., (1995, see earlier) used the SDSA to compare driving ability of patients with Alzheimer's disease (n=19) and 'normal' elderly patients (n=48). All of the AD patients and 48% of normal elderly patients failed the SDSA. Unfortunately subjects were not tested on the road.

In an American study comparing risk factors for crashes among older drivers in rural communities, Foley et al., (1995) found the crash rate was about 20% less than the national average for those aged 65 and over. Increased crash risk was associated poor performance on a free recall memory test (RR=1.4, $p<.05$).

Fitten et al., (1995) tested two groups of mildly demented patients (15 AD and 12 vascular dementia) and three age and health-matched control groups on laboratory tests (MMSE, clock drawing and computerised tests of visual tracking, short term memory, vigilance and divided attention) and on-road driving. Driving scores for the demented patients differed significantly from all three control groups. Tests that were significantly correlated with the driving score were short term memory, visual tracking and MMSE. There was a significant negative correlation between the driving score and number of collisions and moving violations per 1000 miles driven.

Fox and co-workers (1997) found the MMSE to be a significant predictor of on-road driving ability in demented patients but that other neuropsychological tests were not. This is probably explained by the fact that the MMSE is a composite score of cognitive abilities, whereas other cognitive tests were considered in isolation. This is consistent with findings that groups of tests, rather than individual tests scores are better predictors of driving ability (Simms and O'Toole, 1994; Engum et al., 1989; 1990; Nouri and Lincoln, 1987).

1.14.2.2 Section summary

Neuropsychological tests have been used in an attempt to predict driving ability in people with dementia. However, studies are typically too small to provide definitive answers, or generalisability of the findings is affected by disease severity and progression, subject and setting selection or retrospective study designs (Odenheimer, 1993). Studies examining the correlation between neuropsychological tests and driving ability demonstrate high correlations but are not often replicated, raising the question of whether the same cognitive tests used in clinical settings would provide the same answers (Lundberg et al., 1997). Further research is needed to determine the relationship between the presence and severity of dementia and driving safety (Kasniak 1991). In view of the growing numbers of elderly drivers and inevitable increase in elderly drivers with dementia, the question of whether a simple, cognitive assessment, known to have predictive validity in stroke patients, can predict fitness to drive in people with dementia, is an important one.

1.15 Chapter summary

The ability to drive is a significant component of quality of life. It is therefore important that those who are fit may continue to drive for as long as possible. However, for safety reasons those who become unfit should be identified. As part of the normal ageing process and as a result of trauma or disease, the brain systems which underpin the ability to drive safely may deteriorate, although exactly which cognitive impairments or to what extent they make a person unsafe remains unknown. Current methods of driving assessment fail to address the question comprehensively in that they omit cognitive factors which may be more important than physical disabilities. Clearly there is a need for empirical evidence about which functions are necessary for safe driving, so that methods of determining safe from unsafe drivers may be sought.

There is reasonable evidence to suggest that cognitive abilities are important for driving. Research has indicated that information processing speed, attention and executive abilities are useful indicators of driving fitness among people with brain damage. However, early studies indicating useful cognitive tests were often methodologically limited. Many involved tiny samples or mixed different types of brain damage. Some based their findings on correlational analyses, which failed to find clear relationships between cognitive abilities and driving and lacked clear cut-off scores thereby restricting interpretation and practical application in clinical settings. The failure to apply theoretical models also meant post hoc interpretations were applied to findings, thus raising concern about the meaning of significant correlations (Kenny, 1979). More importantly, many studies failed to relate cognitive test performance to actual on-road driving, which although imperfect is thought to be the best criterion to judge safety on the road (Anonymous, 1990; McKenna, 1998; Odenheimer, 1993; Pentland et al., 1992). Therefore much previous research has been problematic, in that it has failed to find clear relationships between cognitive performance and on-road driving ability and has lacked cross validation, in that tests found useful for assessing some types of brain damaged patients have not been cross validated on a second group of similar patients or on patients in other diagnostic groups.

Among people with stroke there is reasonable evidence to suggest that cognitive skills are important for driving and a cognitive screening test, which is predictive of on-road driving performance has been developed. A study is now needed to determine exactly which cognitive abilities are assessed by the Stroke Drivers Screening Assessment.

The lack of a valid clinical measure for other diagnostic groups means clinicians are often forced to rely on reports from family members. Clearly an objective evaluation would be preferable (Odenheimer, 1993). Without an objective, reliable criterion against which to make a decision about stopping driving there remain some inconsistencies, in that some unsafe drivers continue to drive whilst others who may be safe are refused a licence (Brouwer and Withaar, 1997). One question that has arisen is whether the SDSA can be used for people with other acquired neurological disabilities such as Parkinson's disease, traumatic brain injury, multiple sclerosis or dementia.

Many studies have highlighted the need for driving assessments to be carried out on the public roads and to be sufficiently long and detailed to allow higher order cognitive processes to be tested and higher level driving decisions to be made (Brouwer and Withaar, 1997; Hartje et al., 1991; Korteling and Kaptein, 1996; Odenheimer et al., 1994; Van Zomeren et al., 1987). However, the validity of the on road test is seldom questioned and it remains unknown whether this is a good enough criterion measure against which to validate cognitive tests. Since this was the criterion used to validate the SDSA, it would seem important to check the reliability of this measure.

Consequently the aims of this research were:-

i) To determine which cognitive abilities are assessed by the Square Matrices and the Road Sign Recognition subtests of the SDSA.

ii) to determine whether the SDSA can be used to predict fitness to drive in patients with acquired neurological disabilities other than stroke.

iii) to check the criterion validity of the 'Gold Standard' of driving ability used in studies to validate the SDSA.

Chapter 2

CONCURRENT VALIDITY OF THE STROKE DRIVERS SCREENING ASSESSMENT (SDSA)

2.1 Aim

To determine which cognitive abilities are assessed by the Square Matrices and the Road Sign Recognition subtests of the SDSA.

2.2 Introduction

The Stroke Drivers Screening Assessment (SDSA) was designed to predict whether stroke patients are fit to resume driving. In the development, 79 stroke patients were assessed on a battery of fourteen cognitive tests. Their 'fitness to drive' a car was then tested on the public roads by a Department of Transport approved driving instructor (ADI). The patients were graded overall as 'pass', 'borderline' or 'fail'. The cognitive tests which best predicted 'on-the-road' performance i.e. best discriminated between the ADI's gradings, were selected for use as a screening procedure - the SDSA (Nouri et al., 1987; Nouri and Lincoln 1992). Patients who fail the assessment are advised not to drive. Those who pass may then be referred to a specialist driving assessment centre.

The initial battery of cognitive assessments was chosen following extensive discussions with clinical psychology colleagues. It was based on tests which had been found useful in clinical practice (Smith, 1980), used in previous research (Sivak et al., 1981) or assessed skills that were thought to be relevant to driving in brain damaged patients. Where possible, standardised published assessments were used. However, most of the clinical assessments of executive functions were regarded as inappropriate for stroke patients. For example, the Modified Card Sorting Task (MCST) (Nelson, 1978) was considered too lengthy; earlier versions of the Stroop (Jenson and Rohwer, 1966) were considered too complex and liable to be influenced by neglect, and the Cognitive Estimates (Shallice and Evans, 1978) and Word Fluency (Benton and Hamsher, 1976) tests required language skills which were likely to have been affected in a significant proportion of patients.

A children's game, 'What's in the Square?'(E.J. Arnold Ltd.) had seemed useful clinically (Smith, 1980) and had the advantage of having face validity, as it included items relating to driving (pictures of lorries and cars travelling in different directions). A modified version of this, the 'Square Matrices', was included and proved to be one of the best predictors of 'on-the-road' performance (Nouri et al., 1987). On the basis of work by Smith (1980) and the predictive ability for driving, the Square Matrices was thought to measure reasoning abilities.

A Road Sign Recognition test was developed for inclusion in the test battery as a measure of visual perception with face validity for driving, as no standardised measures were available. The Road Sign Recognition test (RSRT) also proved to be a good predictor of 'on the road' performance. Although developed as a measure of road sign knowledge, the task required subjects to interpret information from line drawings, relate this information to road situations and decide which road sign (out of a maximum of 20) best matched the situation. Time constraints imposed on the test (12 situation cards in three minutes) meant subjects had to work methodically and quickly. Nouri and co-workers

(1987) believed this task measured more than just memory for road signs and may also have involved planning, organisational skills and reasoning ability. Therefore, while two of the subtests in the SDSA had predictive validity for driving performance, it was not known which cognitive skills they assessed. The SDSA was being widely used to screen stroke patients wishing to resume driving and therefore it seemed important that these assessments were investigated further. The purpose of this study was to examine the content and concurrent validity of the Square Matrices and Road Sign Recognition subtests of the SDSA.

2.3 Methods

2.3.1 Subjects

Stroke patients were identified from three sources:

i) records of patients assessed by the Derby Regional Mobility Centre (DRMC) in the previous year

ii) a register of patients admitted to the Derbyshire Royal Infirmary Stroke Unit between 30th November 1995 and 26th April 1997

iii) patients from Nottingham who were included in the multicentre Trial of Occupational Therapy and Leisure (TOTAL) (Parker, 2000). These were patients' randomised to receive Occupational Therapy intervention and who wished to resume driving.

All patients had to live within 30 miles radius of Nottingham or Derby and give their consent.

Patients from source ii) were reviewed six months after discharge and excluded if they:-

Had a Barthel score of less than 10

Lived in a nursing or residential home

Were not driving in the three months before their stroke

Were severely aphasic

Patients scoring less than 10 on the Barthel ADL index or who were living in nursing or residential care were considered likely to be unfit to resume driving. Barthel ADL Index's were administered by post. Non-response was followed up by telephone.

Consenting subjects from the three referral sources were randomly allocated to two groups, One and Two. This determined the order of assessments (see section 2.3.3.1).

2.3.2 Procedure

In addition to demographic details, a record was kept of the date and side of lesion. Subjects meeting the study criteria were contacted by letter (Appendix 2.0) and asked if they would be willing to participate in a study to improve an existing cognitive assessment. They were assured that taking part in the study would not involve driving a car. Subjects were visited at home by the researcher or by one of three psychology undergraduates and assessed on a series of cognitive tests (see 2.3.3). Psychology students were trained in methods of test administration by the researcher and each was observed by the researcher assessing one patient. The tests included the SDSA and validated tests of cognitive abilities assessing cognitive functions thought to be important for the performance of the SDSA.

2.3.3 Cognitive Tests

1. <u>The Stroke Drivers Screening Assessment (Nouri and Lincoln, 1994)</u>

The Stroke Drivers Screening Assessment (SDSA) consists of three tests. The *dot cancellation* task is a test of concentration and visual inattention. It is a shortened version of the standardised Bourdon Wiersma stipple test (Grewell, 1953). Subjects are presented with a sheet containing 625 groups of three, four and five dots. They are required to cancel out all groups of four dots within a time limit of 15 minutes. Subjects are given a practice row and mistakes from this are pointed out by the researcher. They are then told "It is more important to be accurate than fast; start when you are ready". The time taken to complete the task, the number of errors (groups of four dots that were missed) and the number of false positives (groups of three and five dots cancelled in error) are recorded.

This is followed by the *'Square Matrices'* which is in two parts. In the first part, subjects are presented with a board depicting a sixteen-square matrix. A set of large arrows facing in different directions is placed along the left-hand side and a set of small arrows across the top. Subjects are given a set of sixteen cards depicting lorries and cars travelling in different directions. They are instructed to position these cards so that each lorry is travelling in the same direction as a large arrow and each car in the direction of a small arrow (as shown in Fig 2.0).

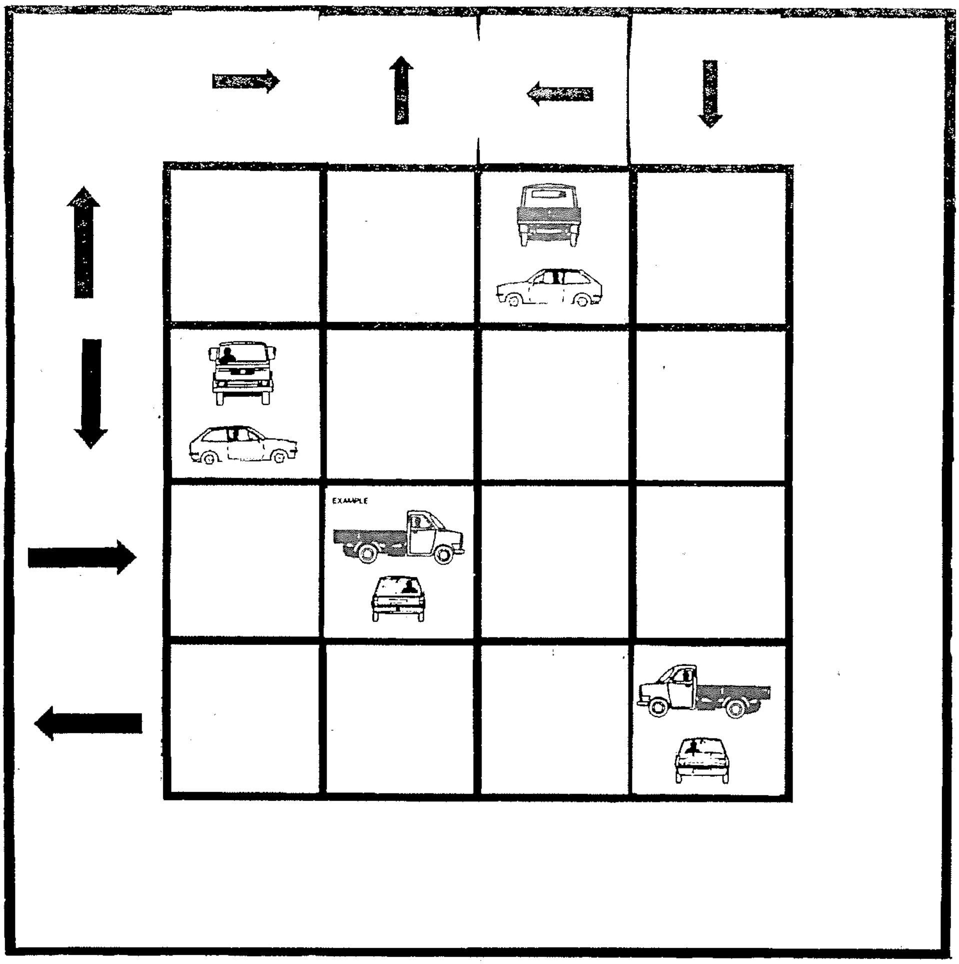
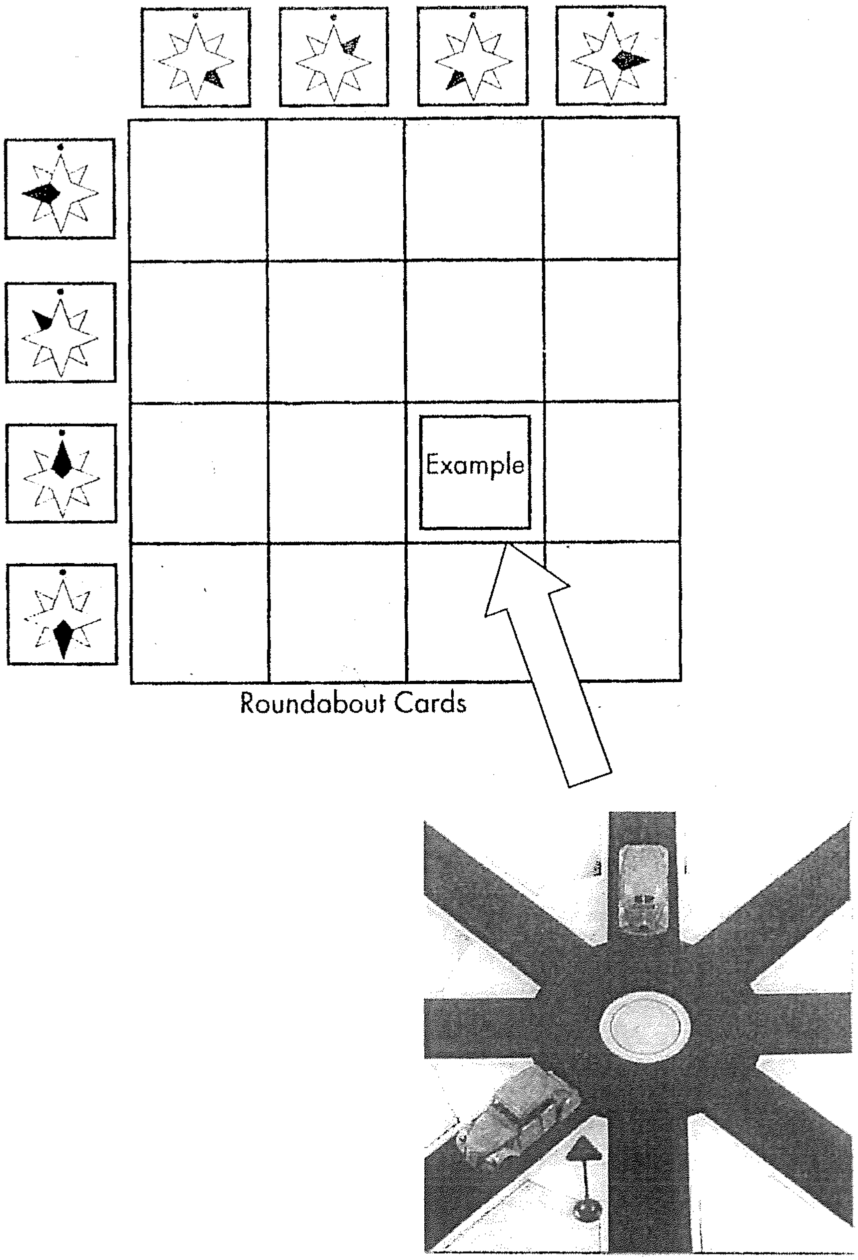


Fig. 2.0: Square Matrices -Directions

The second part is more complex. A set of eight compass cards, each with one black arm, are placed along the left side and across the top of the board. The black arm of the compass card indicates a direction of travel. Subjects are presented with a set of 28 cards. The cards are photographs of two 3D model cars travelling in different directions (Fig. 2.1).



(Fig. 2.1). Square Matrices Compass Cards

Subjects are required to position the cards so that both vehicles on the cards are travelling in directions indicated by the compass cards. There are more cards than available spaces. Both parts have a time limit of five minutes. Both parts are scored out of a maximum of 32, i.e. one point for each correctly placed vehicle.

Finally subjects have to match a set of road signs with twelve pictures of road situations in a time of three minutes (Fig 2.2). This is the *Road Sign Recognition test* (RSRT). One point is allocated to each correctly matched road sign (maximum 12).

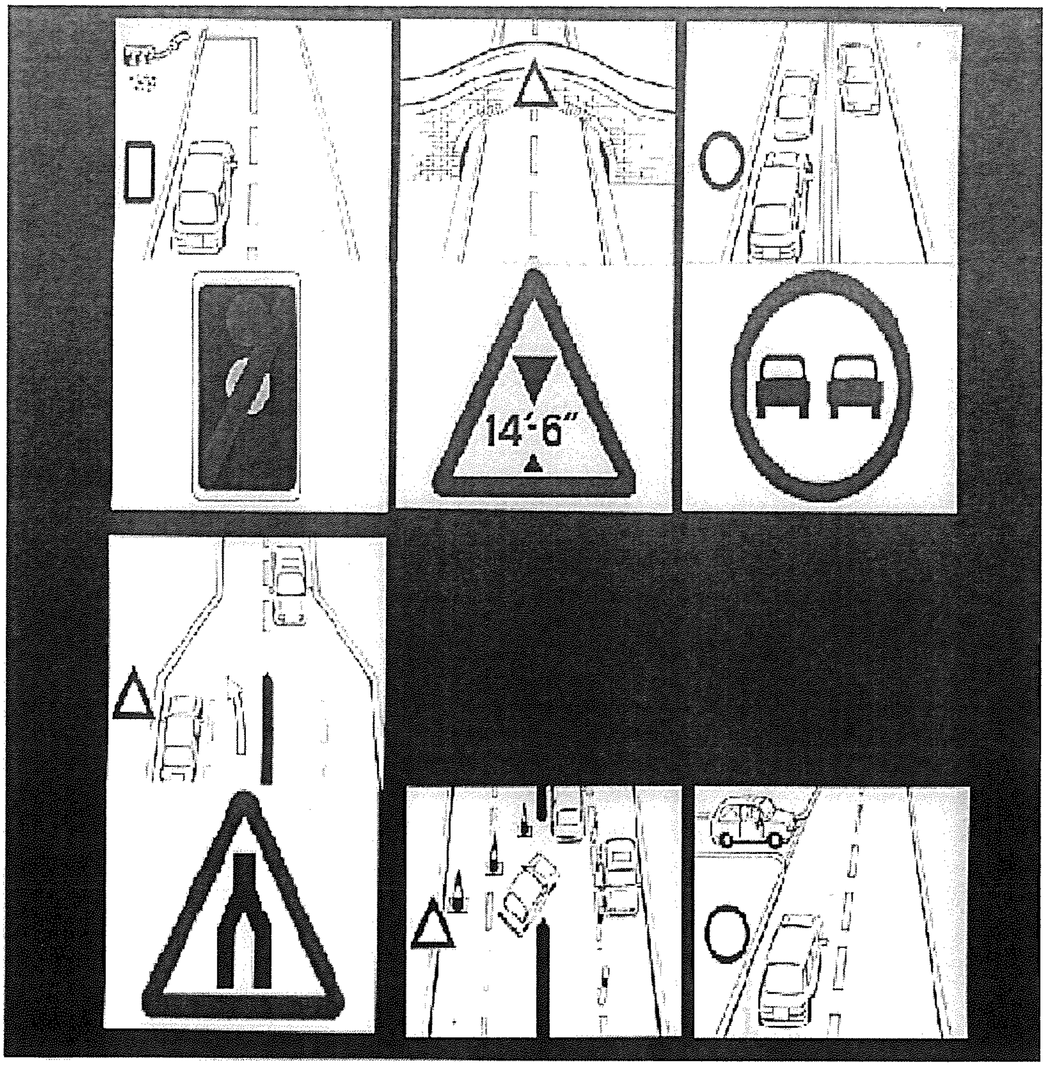


Fig 2.2 Road Sign Recognition

Scores from different parts of the test are entered into two equations. A 'Pass' equation and a 'Fail' equation (Appendix 2.1). The equations (derived from discriminant analysis based on samples of stroke patients used in the development work) take account of the predictive value of each test and its weight in the overall prediction of 'fitness to drive'. The outcome (i.e. overall 'Pass' or 'Fail') prediction is the equation with the higher value. Not all scores from each task are entered into the equations. The scores used are:-

Time taken (in seconds) to complete the Dot Cancellation test [A]

Number of Dot Cancellation-false positive errors [C]

Square matrices-Compass Cards score [E]

Road Sign Recognition score [F]

2. Recognition Memory Test (faces), (Warrington, 1984)

The Recognition Memory Test (RMT) was designed to assess material specific memory deficits for adults in the 18 - 70 years age range (Warrington, 1984, Lezak, 1995). Memory for faces is selectively impaired in adults with right hemisphere lesions. Non verbal memory deficits are associated with right hemisphere damage (Milner, 1966) and may also result from other neurological conditions e.g. head injury (Smith, 1974).

The test consists of 50 photographs of unfamiliar male faces (mostly white) and 50 'distracter' faces drawn from the same pool. The facial types vary widely. The 50 stimulus faces are presented to subjects at the rate of one every three seconds. Subjects are told to say 'yes' if they think the man in the photograph looks pleasant and 'no', if they think he looks unpleasant. Subjects are told there are no right or wrong answers, but that they are required to make a judgement about each face. This is to ensure subjects attend to each photograph, a method found to result in more consistent scores in earlier research (Warrington and Ackroyd, 1975). Immediately after the stimulus faces have been presented, subjects are told, "I am now going to test your memory for the faces you have just seen in the pack". Each stimulus photograph is re-presented, together with a distracter photograph (mounted side by side). Subjects are required to point to the face they have seen previously. The position (right or left) in which the photographs are mounted on the card is random and the order in which the stimulus photographs appear, differs from the first presentation.

Scores on the RMT reduce significantly with age, particularly so after the age of 65 (Delbecq-Derouesne and Beauvois, 1989). In a study by Diesfeldt (1990), neither education nor gender affected performance on either Recognition Memory Test Words (RMW) or faces (RMT-faces), although positive correlations between both RMW and RMT-faces and WAIS Vocabulary (r =0.38, r =0.26) and Raven's Matrices (r =0.45, r =0.33) (Warrington, 1984) indicated that mental abilities should be considered when interpreting scores. Significant correlations between RMT-faces scores and performance on Ravens' Progressive Coloured Matrices have been found for both demented and control subjects (r=0.45, r =0.48), which Diesfeldt (1990) interpreted as a reflection of the role of visuoperceptual discrimination in the RMT-faces task. The RMT-faces has been shown to be 100% effective in discriminating between demented and non-demented subjects (Diesfeldt, 1990).

The RMT-faces was chosen because it is quick and easy to administer making it an ideal screening measure for mild memory deficits (Leng and Parkin, 1990). It was considered appropriate for stroke patients since it allows retention to be assessed in patients with impaired language (Warrington, 1984) and is not restricted by motor disorders (Lezak, 1995). The faces test is sensitive to deficits in patients with both right and left sided lesions (Warrington, 1984). The Recognition Memory Test for faces was included as a measure of visual memory to determine whether the SDSA subtests, in particular the Road Sign Recognition Task, were measuring aspects of visual memory.

3. Stroop Neuropsychological Screening Test (Trennery et al., 1989)

This is a standardised version of the 'Stroop procedure', based on work by Stroop (1935) and Jenson and Rohwer (1966), who found that it takes longer to name the colour of a colour word when the word is printed in a different coloured ink to that stated by the word, than it does to read the word. This delayed naming response or 'interference effect' has been attributed to response conflict, failure of response inhibition and failure of selective attention (Dyer, 1973; Zajano and Gorman, 1986). It has been suggested that the ability to perform well on this procedure is linked to good concentration and the ability to "ward off distractions" (Lezak, 1995). Increases in interference effect may be age related and intellectual level may also contribute to performance (Comalli, 1965; Comalli et al., 1962; Das, 1970; Regard, 1981). The interference effect is more pronounced in brain damaged subjects than their normal controls (Nehemikis and Lewinsohn, 1972). Little difference has been observed between subjects with right and left hemisphere lesions (Nehemikis and Lewinsohn, 1972). Subjects with frontal lobe damage perform worse than those with temporal or posterior lesions and the performance of subjects with left frontal damage is more impaired than those with right frontal damage (Perret, 1974; Holst and Villki, 1988).

The test involves two trials. Subjects are presented with two sheets (one at a time) of 112 words depicting colour names (red, blue, green or tan). The words are printed in non-matching coloured inks (red, blue, green or tan) to those stated by the words. In the first trial subjects are required to read the words aloud as quickly as they can, correcting any mistakes as they go. In the second, subjects have to read aloud the colour of the ink in which the word is printed. Two minutes are allowed for each trial. Each trial is scored by deducting the numbers of errors and corrected errors from a maximum of 112 for each task. The colour-word task produces the interference effect in which the colour name hinders the verbal report of the colour of the ink (Trenerry et al 1989).

The Stroop test was chosen as a measure of selective attention and concentration. The version used in the present study (Stroop Neuropsychological Screening Test - SNST) was designed to overcome methodological and practical problems evident in other versions, such as the difficulty encountered by some brain damaged subjects to read across rows. In the SNST, stimuli are organised in columns and the colours chosen are one syllable words. This controls for the effect of multiple syllable words on response time (Trenerry et al., 1989). The SNST has been standardised and validated on adults over eighteen years. It was chosen for the speed and ease with which it can be administered and because this can be done by those without formal neuropsychological training.

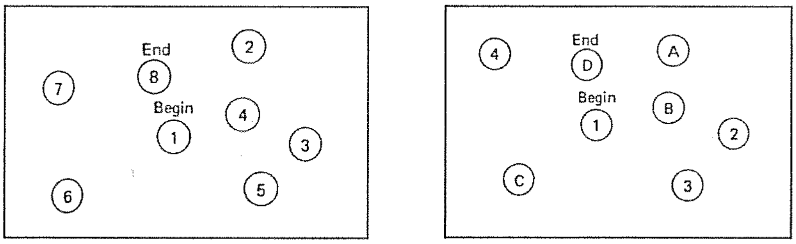
4. Trail Making Test (Halstead-Reitan Neuropsychological Test Battery. Reitan and Wolfson, 1993)

The Trail Making Test (TMT) is a measure of visual, conceptual and visuomotor tracking with a motor component (Lezak , 1995). It is clinically useful as a test of visual scanning and tracking problems which may reflect mental sequencing and the subjects' ability to cope with complex stimuli or more than one thought at a time.

Performance on the test is affected by motor speed (Schear and Sato, 1989). Age (Ernst 1987; Stuss et al, 1987; Warner et. al., 1987) and educational level (Boll and Reitan, 1973; Bornstein, 1985; Ernst, 1987) have also been shown to affect performance. These effects predominate on part 'B'.

Excessive differences in time taken to complete the two parts is thought to indicate difficulties in complex conceptual tracking (Lezak, 1995). Slow performances on either or both parts are indicative of brain damage (Armitage, 1946; Reitan, 1958; Spreen and Benton, 1965). In patients with mild head trauma, slowing has been found to increase with damage severity (Leininger et al., 1990), although no significant differences were found between subjects with mild or more severe concussion (Leninger et al., 1990) or between mildly injured subjects and controls (Stuss et al., 1989). This is thought to be attributable to the large within-group variations in performance on part 'B' (Lezak, 1995).

The test comprises two parts, 'A' and 'B'. Each part includes a practice and a test trial. In part 'A', subjects are presented with a sheet of paper (practice trial) depicting circles numbered 1-8. Subjects are instructed to draw lines between consecutively numbered circles "as fast as you can". Subjects are then presented with a sheet depicting circles numbered 1-25 (test trial), which they are instructed to complete the same way, marking out mistakes as they go. In part 'B', subjects are presented with a sheet depicting numbers (1-4) and letters (A-D) (Fig. 2.3), they are required to draw a line between consecutive numbers and letters.



Part A Part B

Fig. 2.3 Practice Samples of the Trail Making Test

They are instructed to start with a number, followed by a letter and so on until they reach the end. For example "Draw a line from 1 to A, from A to 2, 2 to B and so on...". The instructions are demonstrated by the researcher who points to the correct numbers and letters on both the practice and test trials whilst giving the instructions. The test trial sheet depicts numbers (1-13) and letters (A-L). Subjects are instructed to do this in the same way and are told to draw the lines as fast as they can. The total time taken (in seconds) for each test trial is recorded. The time is then converted into credits (see Appendix 2.2). A maximum of 10 credits is awarded to times of less than 38 seconds for part A and less than 43 seconds for part B. The total score is obtained by summing credits for parts 'A' and 'B' (Reitan, undated).

This test was chosen as a short measure of divided attention and complex conceptual tracking, which could be used to determine whether the RSRT and Square Matrices subtests also measured these executive skills.

5. Cognitive Estimation Test (Shallice and Evans, 1978)

This is a test of practical judgement, which tests the subjects' ability to make estimates and mental projections and to apply what they know. It is a measure of frontal lobe damage, requiring judgement in "novel" situations (Lezak, 1995).

In constructing the test, Shallice and Evans (1978) found patients with anterior lesions gave more bizarre responses than those with posterior lesions. They also found some questions evoked more bizarre responses than others did.

The test consists of a set of ten questions, for example "What is the length of the average man's spine? and "How heavy is a full pint bottle of milk?". The questions are read aloud by the researcher and subjects are asked to give a response. They are told to "Guess as near as you can", if they don't know the answer. Subjects' responses are converted to points according to strict criteria. The points are based on responses given by the control group performance (Shallice and Evans, 1978) (Appendix 2.3). Each correct answer scores 0 points. Less accurate answers accrue a greater number of points.

The test was chosen as a measure of executive function, since it was thought that the Square Matrices subtests of the SDSA might require executive skills.

6. Verbal Descriptions of Road Situations (VDRS), (Melly, 1997, unpublished B.Sc. Thesis)

This test was developed by the researchers. Its purpose was to determine whether the Road Sign Recognition sub test of the SDSA measures road sign knowledge or whether it involves more complex cognitive abilities.

Subjects are presented with a set of 20 road signs (these are the same road signs used in the SDSA Road Sign Recognition Task). The cards are laid out in front of the subject, so that all 20 can be seen. A set of 12 descriptions of road situations (Appendix 2.4) are then read aloud to the subject, one at a time. Subjects are required to point to the road sign which best matches the description of the road situation they have heard. For example "On a road where a set of traffic lights is out of action, which road sign might you expect to see?" The subject points to the sign that indicates, 'traffic light out of order', i.e. traffic light with a red line through it. One example is given to the subject to ensure the instructions have been understood. This is followed by the 12 situations. The test is scored out of a maximum of 12, i.e. one point for each correctly identified sign, excluding the example.

It is thought that the VDRS tests knowledge for road signs, without requiring visual reasoning skills.

7. Visual Object and Space Perception Battery Cube Analysis (Warrington and James, 1991)

The Visual Object and Space Perception Battery (VOSP) consists of four tests of object perception and four tests of space perception, selected to minimise the praxic component. Each test focuses on one component of visual perception

(Warrington and James, 1991). The Cube Analysis (Newcombe, 1969) is an adaptation of a test devised by Binet, that requires spatial analysis of a two-dimensional representation of bricks into its constituent parts (Binet and Simon, 1908). The test is also sometimes referred to as the Block Counting task (Terman and Merrill, 1973) or Cube Counting (McFie and Zangwill, 1960) and is a measure of reasoning ability (Lezak, 1995). Studies comparing patients with right and left sided damage have found those with right sided damage to have more impaired performance (Newcombe, 1969, McFie and Zangwell 1960; Warrington and Rabin, 1970) and significantly more subjects with right hemisphere than left hemisphere lesions obtained a deficit score on the test than did normal controls (Warrington and James, 1991).

Subjects are presented with outline drawings each representing a three-dimensional arrangement of cubes (see fig 2.4).

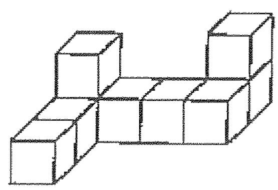


Fig. 2.4: Example from VOSP Cube Analysis

There are two practice items, each comprising three cubes, followed by ten test stimuli (Warrington and James, 1991). The number of cubes in the test stimuli increases from five to twelve. Some 'hidden' cubes are included in the arrangements. Subjects are shown the practice items and asked how many solid cubes are represented in the drawing. Response errors on the practice items are corrected and the task re-explained. If the subject is unable to count the cubes correctly on both practice items, the task is abandoned. The practice items are followed by the ten test stimuli. The first omission error is corrected by asking subjects to remember cubes hidden "underneath other cubes". The total number of correct responses is recorded out of a maximum of ten.

The test was chosen to measure spatial ability, namely the subjects' ability to interpret two-dimensional representations of 3D objects and space.

2.3.3.1 Test Administration

The order of assessments was determined by random allocation to two groups. Subjects in Group One were tested on the SDSA first, followed by the additional cognitive tests in a fixed order (Recognition Memory Test, Stroop, Trail Making Test, Cognitive Estimates, VDRS and VOSP Cube Analysis) (see fig.2.5). Group Two were tested on the additional cognitive tests, followed by the SDSA. This was to overcome any order effect and to determine whether performance on the SDSA was influenced by the Verbal Descriptions of Road Signs test (VDRS) and whether performance on the VDRS was influenced by the SDSA Road Sign Recognition test (RSRT).

Group One	Group Two
⇩	⇩
SDSA	**Recognition Memory Test** **Stroop** **Trail making Test** **Cognitive Estimates** **VDRS** **VOSP Cube Analysis**
⇩	⇩
Recognition Memory Test **Stroop** **Trail Making Test** **Cognitive Estimates** **VDRS** **VOSP Cube Analysis**	**SDSA**

Fig. 2.5 Order of cognitive test administration

2.3.4 Data Analysis

Data were treated as non-parametric. Mann-Whitney 'U' tests were used to identify differences in cognitive test results according to order of test administration (whether the SDSA was done first [group One] or last [group Two]).

The relationships between subjects' performance on the SDSA subtests and performance on the additional cognitive tests was explored using Spearman's rho correlations. Parametric methods (Principal Components Analysis and Multiple Regression) were used where no non-parametric equivalent exists, to further explore the relationships between the additional cognitive tests and the SDSA subtests. Rigid screening and transformations were used to ensure fit with the assumptions of multivariate analysis prior to analysis. The goal of Principal Components Analysis was to extract maximum variance from the data set with each component and thus identify a small set of variables or factors that explained most of the total variation in the original variables (Grimm and Yarnold, 1997). The factors were then used to identify theoretical dimensions implied by the pattern of variables that were the most important constituents of that factor. The purpose of multiple linear regression was to assess the relationship between each SDSA subtest (dependant variable) and the established cognitive tests (independent variables) and to determine which test or tests best predicted SDSA performance (Tabachnick and Fidell, 1996).

Analysis was carried out using SPSS version 6.3.1 for windows (Norušis, 1996). Checking of a random sample of 15% of the data set was carried out by an independent assessor.

2.4 Results

2.4.1 Patient Characteristics

i) Of the 147 patients identified from records of patients assessed by the DRMC between November 1995 and December 1998, 31 lived outside the study area, seven were novice drivers and three had been previously assessed on the Stroke Drivers Screening Assessment. One hundred patients were considered for inclusion in the study; of these:-

Sixteen refused consent

Eight were not seen by one student during the time she had available

Five were visited by a student who subsequently became ill and the results were lost to analysis

Five could not be contacted. (These patients were contacted by letter and did not respond. No contact telephone number was available).

Three were severely aphasic

Two had had another stroke

One became ill

One had a stroke secondary to a brain tumour

One had not driven for some years

One spoke no English

One patient was caring for his wife who was terminally ill

Therefore sixty-two patients were recruited and assessed.

ii) Of the 102 patients admitted to the DRI Stroke Unit between 30 November 1995 and 26 April 1997, Twenty-five were not driving in the three months before their stroke or had never driven.

Twenty-one were living in nursing or residential care facilities or had been transferred to outlying hospitals.

Twenty had died.

Seven refused consent

Five could not be contacted

Four had Barthel scores of less than ten

Two were severely aphasic

Two lived outside the study area

One patient was re-admitted to hospital

One patient had undergone larengectomy

One had already been seen by DRMC

One patient was overlooked by the researcher

Therefore, twelve patients were recruited and assessed.

iii) Of the 25 Nottingham patients referred by treatment therapists from the TOTAL trial,

Two refused consent

Two could not be contacted

One had previously been assessed on the SDSA

One was not available for assessment during the study period

Therefore, nineteen patients were recruited and assessed.

Overall a total of 93 patients were recruited from the three sources and assessed on the battery of tests. Demographic details of subjects may be found in Table 2.0.

Table 2.0: Demographic details of patients in the study

Sex	men women	81 12
Age	mean SD range	63.3 12.4 22 - 83
Time since onset (months)	median IQR range	15.2 8.8 - 24.3 2.5 - 111.6
Side of body affected	right left no clear lateralisation	44 46 3

Forty-five patients completed the SDSA first. Mann-Whitney 'U' tests were used to identify differences in cognitive test scores on the Road Sign Recognition test and the Verbal Descriptions of Road Signs test between patients assessed on the SDSA first (Group 1) or last (Group 2). Seven patients who were given a different version of the VDRS, were excluded from the analysis (See Table 2.1). In the first version of the VDRS test, only specific road signs were presented with each verbal description of a road situation. This was considered too simple and the test was altered so that patients had to choose from all 20 road signs with each verbal description.

Table 2.1: Differences in RSRT and VDRS scores according to order of SDSA administration.

	Group 1 (SDSA first)		Group 2 (SDSA last)		U†	p - 2 tailed	95% CI
VDRS	median IQR range	9 8 – 9 3 – 12	median IQR range	11 9 – 11 7 – 12	704	0.08	0.0, 2.0
RSRT	median IQR range	6 3.5 - 6 0 - 12	median IQR range	8.5 6 – 8.5 2 - 12	505	<0.001	1.0, 4.0

† Mann-Whitney U test, CI = Confidence Interval

There were no significant differences between the two groups on VDRS scores, according to order of SDSA administration. However, scores on the RSRT did differ significantly between the two groups. Patients who completed the VDRS first performed significantly better on the RSRT.

Relationships between the SDSA subtests were explored using Spearman's rho correlations (see Table 2.2). Dot Cancellation is a negatively scored test, so any negative correlations between Dot Cancellation errors and false positive scores or time taken to complete the task, do not imply an inverse relationship. Dot cancellation test scores were missing for one patient, who was unable to concentrate or visually attend to the task.

Table 2.2: Spearman's Rho correlations between the SDSA subtests.

	Dot Cancellation Time	**False Positives**	**Compass Cards**
Dot Cancellation Time			
False Positives	0.17 p=0.10		
Compass Cards	-0.35** p<0.01	-0.20 p=0.06	
Road Sign Recognition	-0.30** p=0.01	-0.20 p=0.06	0.52** p<0.001

**Correlation is significant at the .01 level (2-tailed).

The score for the Square Matrices-Compass Card test was significantly positively correlated with Road Sign Recognition and significantly negatively correlated with Dot Cancellation time, suggesting a relationship between performance on the Dot Cancellation test and performance on the Square Matrices-Compass Cards and Road Sign Recognition (RSRT) sub tests. Since Dot Cancellation is a known test of concentration and visual inattention, this would suggest similar abilities are measured by the Square Matrices, in particular the Compass Card test. The RSRT was also significantly positively correlated with the Square Matrices-Compass Cards, suggesting Square Matrices and Road Sign Recognition both measure similar cognitive abilities. Time taken to complete the Dot Cancellation test was also significantly negatively correlated with performance on the RSRT, suggesting this test also requires concentration and visual attention. However correlation was only moderate (r_s -0.30, $p<0.01$). The highest correlation was that between the Square Matrices-Compass Cards and the RSRT. Correlation between sub tests is not surprising since they all measure abilities which relate to driving. However, the absence of multicollinearity between all SDSA subtests suggests that each test contributes unique information to the overall SDSA performance.

In order to determine which cognitive abilities are measured by the Square Matrices and Road Sign Recognition Tests, relationships between the additional cognitive tests and the SDSA sub tests were explored using Spearman's rho correlations. Dot Cancellation and Cognitive Estimates are negatively scored tests i.e. poorer performance is indicated by higher test scores, therefore negative correlations between these and other tests do not reflect an inverse relationship in ability. Scores for Cognitive Estimates and Trail Making were missing for one patient who was aphasic. Scores for the Stroop were missing in three cases, due to aphasia and colour blindness. Results are shown in Table 2.3.

The Square Matrices-Compass Card test was significantly positively correlated with VOSP cubes (r_s 0.24, $p<0.05$) and with the Recognition Memory Test suggesting measurement of spatial abilities and visual recognition, although correlation was not high. Significant negative correlation between the Square Matrices-Compass Cards and Cognitive Estimates (r_s -0.27, $p<0.01$) and high significant positive correlations between the Stroop and the Square Matrices-Compass Cards (r_s 0.56, $p<0.001$), and between the Trail Making Test and Compass Cards (r_s 0.56, $p<0.001$) suggest this sub test measures reasoning abilities and attention.

The RSRT was significantly positively correlated with VOSP cubes (r_s 0.21, $p<0.05$), the Stroop (r_s 0.45, $p<0.001$) and the Trail Making Test (r_s 0.49, $p<0.001$) suggesting this test also measures reasoning abilities, attention and visuospatial abilities.

Moderate significant correlation between the Stroop and Dot Cancellation-time (r_s -0.36. $p<0.01$) and significant negative correlation between Dot Cancellation-errors and VOSP cubes, confirms this SDSA sub test requires visuo-spatial abilities and concentration.

Bivariate correlations, using Spearman's rho were carried out to relate patients' performance on the additional cognitive assessments to the Verbal Descriptions of Road Situations. Seven patients who were administered the original version of the VDRS were excluded from the analyses.

There were significant correlations between patients' scores on the Verbal Descriptions of Road Signs and the Stroop (r_s 0.47, $p<0.001$), VOSP cubes, Trail Making and the RMT, suggesting this test measures spatial and executive abilities, mental sequencing and memory.

Table 2.3: Spearman's rho correlations showing relationship between SDSA and additional cognitive tests (SDSA highlighted).

	Dot Cancel[n] Time	**Dot Cancel[n] False Positives**	**Compass Cards**	**RSRT**	Stroop	Cognitive Estimates	Trail Making	VDRS	VOSP
Dot Cancel[n] False Positives	**0.17 p=0.10**								
Compass Cards	**-0.35** p<0.01**	**-0.20 P=0.06**							
RSRT	**-0.30** p<0.01**	**-0.20 p=0.06**	**0.52** p<0.001**						
Stroop	-0.36** p<0.01	-0.00 p=0.97	0.56** p<0.001	0.45** p<0.001					
Cognitive Estimates	0.08 p=0.48	-0.042 p=0.69	-0.27** p=0.01	-0.04 p=0.72	-0.19 p=0.07				
Trail Making	-0.58** p<0.001	-0.09 p=0.42	.56** p<0.001	0.49** p<0.001	0.55** p<0.001	-0.14 p=0.18			
VDRS	-0.31** p=0.01	-0.04 p=0.75	0.33** p<0.01	0.40** p<0.001	0.45** p<0.001	-0.14 p=0.319	0.33** p<0.01		
VOSP	-0.15 p=0.17	-0.12 p=0.28	0.24* p=0.02	0.21* p=0.05	0.06 p=0.58	-0.16 p=0.13	0.05 p=0.65	0.27* p=0.01	
Recognition Memory test	-0.14 p=0.18	-0.13 p=0.24	0.35** p<0.01	0.16 p=0.13	0.35** p=0.00	-0.18 p=0.09	0.18 p=0.09	0.43** p<0.001	0.19 p=0.07

* Correlation is significant at the .01 level (2-tailed)

** Correlation is significant at the .05 level (2-tailed).

Correlation between Verbal Descriptions of Road Situations (VDRS) and RSRT was significant but not high (r_s 0.37, P<0.001) suggesting that whilst both tests may share measurement of some abilities, they are not identical. The VDRS was significantly correlated with VOSP cubes, Stroop, Trail Making and RMT, suggesting this test requires verbal skills, spatial and executive abilities, mental sequencing and memory. VDRS, like its counterpart the RSRT, was significantly correlated with the Compass Card test (albeit to a lesser extent) and with Dot Cancellation time.

Correlations between the RSRT and Trail Making, Stroop and VOSP, but not RMT suggest verbal skills are required more for VDRS than RSRT, whilst RSRT depends more on perceptual abilities than VDRS. Since the SDSA was developed to predict driving ability in aphasic patients who are not precluded from driving, it would seem important that this test is not dependent on verbal skills. The significant negative correlation between Dot Cancellation-time and VDRS suggests mental speed and concentration may be important skills needed for this task.

In order to explore the relationships between the additional cognitive tests and the SDSA subtests further, Principal Components Analysis with orthogonal (varimax) rotation was performed through SPSS FACTORS, for a sample of 92 patients. Prior to analysis, data were screened using various SPSS programmes for fit with the assumptions of multivariate analysis. One case was found to be a multivariate outlier and was therefore excluded from the analysis. This was a man who was severely aphasic and performed poorly on tests requiring verbal skills.

Table 2.4: **Descriptive data for SDSA subtests**

			Skew	K-S Lilliefors	Significance
Dot Cancellation-time	Mean SD Range	526.12 158.99 279-900	1.06	0.15	p<0.001
Dot Cancellation-errors	Mean SD Range	21.52 22.63 0-115	1.96	0.17	p<0.001
Dot Cancellation-false positives	Mean SD Range	3.46 22.49 0-211	8.97	0.41	p<0.001
Square Matrices-Directions	Mean SD Range	25.62 8.66 3 - 32	-1.10	0.22	p<0.001
Square Matrices-Compass Cards	Mean SD Range	18.97 8.59 2-32	-.09	0.10	p=0.03
RSRT	Mean SD Range	6.85 3.25 0-12	-.35	0.09	p=0.11

Normality was examined using the Kolmogorov Smirnov (K-S) Lilliefors test. Score distributions, skew values and significance levels are shown in Table 2.4 for the SDSA and Table 2.5 for the additional cognitive tests. Two of the three SDSA sub tests and three of the additional tests differed significantly from normal. Square Matrices-Directions, Verbal Descriptions of Road Situations and the VOSP cube analysis were severely negatively skewed, with most patients scoring the maximum for each of these tests. Dot Cancellation-errors and false positives were both positively skewed with few patients incurring errors. Therefore Square Matrices-directions, Verbal Descriptions of Road Situations, VOSP and Dot cancellation-errors and false positives were excluded from further analysis. Dot Cancellation time and Cognitive Estimates were mildly positively skewed but transformation using the Square Root made no difference to the outcome, therefore the un-transformed variables were used in the analysis.

Table 2.5: Descriptive statistics and skew values for the additional cognitive tests

			Skew	K-S Lilliefors	Significance
Cognitive Estimates	mean SD Range	5.58 3.36 0 - 15	0.68	0.13	p<0.01
Trail Making Test	mean SD Range	9.01 4.55 1-19	0.09	0.08	p=0.20
VOSP cube analysis	mean SD Range	9.33 1.48 0-10	-3.76	0.40	p<0.001
Stroop	mean SD Range	60.70 29.53 0-112	-0.20	0.06	p=0.20
VDRS	mean SD Range	9.8 1.96 3-12	-0.99	0.18	p<0.001
Recognition Memory Test	mean SD Range	34.49 6.70 12-48	-0.35	0.07	p=0.20

Therefore Dot Cancellation time, Square Matrices-Compass Cards and the RSRT from the SDSA, Recognition Memory Test, Stroop, Trail Making Test and Cognitive Estimates entered the analysis. Missing values were replaced by the mean.

Factorability was tested using Bartlett's test of sphericity (171.06, $p<0.001$) and Kaiser-Meyer-Olkin measure of sampling adequacy (0.82). Both tests suggested the data sample was suitable for factor analysis.

Two factors explaining 61% of the variance were extracted from the analysis. The tests loading most heavily onto the first factor were Trail Making, Road Sign Recognition, Dot Cancellation-time, Square Matrices-Compass Cards and the Stroop. This factor explained 46% of the variance. Those tests loading most heavily on the second factor, explaining 14.5% of the variance were Cognitive Estimates and the Recognition Memory Test. Two of the tests cross-loaded onto both factors. These were the Compass Cards and the Stroop.

The factor loading and pattern of cross loading suggest one main factor may underlie performance on most of the SDSA. Dot Cancellation time, Compass Cards and Road Sign Recognition all load on factor one, together with the Trail Making test and the Stroop. This factor has been interpreted as 'executive abilities and attention'. Loading of the Cognitive Estimates and RMT on factor two and to a lesser extent the Stroop and the Compass Cards on the same factor suggests 'verbal skills' may underlie this factor.

The orthogonally rotated factor matrix, showing factor loadings (above 0.3) for each cognitive test is given in Table 2.6.

Table 2.6: Orthogonally rotated factor matrix

	Factor 1	**Factor 2**
Cognitive Estimates		-0.85
Compass cards	0.71	0.44
Dot Cancellation-time	-0.75	
RMT		0.59
RSRT	0.78	
Stroop	0.64	0.41
Trail Making	0.79	

Multiple regression analyses were carried out to explore more fully the relationship between the tests with the effects of the common variance partialled out. Each SDSA subtest (Dot Cancellation–time, Compass Cards and Road Sign Recognition) was entered as a dependent variable and the established measures as independent variables. The results are shown in Tables 2.7 to 2.10. Missing values were replaced by the mean.

Table 2.7: Multiple Regression Analysis for the Dot cancellation–time

Cognitive Tests	B	Beta	Significance of t
Recognition Memory Test	-3.05	-0.13	p=0.16
Stroop	-0.28	-0.05	p=0.62
Trail Making	-19.16	-0.55	p<0.001
Cognitive Estimates	-0.22	-0.01	p=0.96
Constant	822.08		p<0.001

Table 2.7 shows the prediction for time taken to complete the dot cancellation test. The established cognitive tests together accounted for approximately 36% of the variance adjusting for sample size (Adjusted R Square 0.36). The contributions of the Recognition Memory Test, the Stroop and the Cognitive Estimation test were not significant. Most of the prediction was accounted for by the Trail Making Test.

A combination of test scores predicted performance on the Compass Cards test (see Table 2.8). The Stroop, Trail Making and Recognition Memory tests were all significant predictors accounting for 42% of the variance (Adjusted R Square 0.42). The Stroop and Trail Making tests made the greatest contribution to the prediction.

Table 2.8: **Multiple Regression Analysis for the Compass Cards test**

Cognitive Tests	B	Beta	Significance of t
Recognition Memory Test	0.27	0.21	p=0.02*
Stroop	0.08	0.03	p=0.01**
Trail Making	0.65	0.34	p<0.01**
Cognitive Estimates	-0.25	-0.10	p=0.25
Constant	0.32		p= 0.94

* significant at the 0.05 level.
** significant at the 0.01 level.

Table 2.9 shows the contribution of the additional cognitive tests to prediction of performance on the Road Sign Recognition test. The combination of tests predicted 24% of the variance in performance (Adjusted R Square 0.24). Unique contributions made by the Trail Making Test and the Stroop accounted for most of the prediction.

Table 2.9: Multiple Regression Analysis for the Road Sign Recognition

Cognitive Tests	B	Beta	Significance of t
Recognition Memory Test	0.02	0.04	p=0.69
Stroop	0.03	0.23	p=0.05*
Trail Making	0.26	0.36	p<0.01**
Cognitive Estimates	0.08	0.08	p=0.42
Constant	1.89		p=0.29

* significant at the 0.05 level, ** significant at the 0.01 level.

The SDSA outcome (based on the combination of test scores used in the overall predictive equation) was also entered as a dependant variable and multiple regression analysis used to determine which tests contributed most to the overall predicted outcome (results are shown in Table 2.10). Examination of the plots of the regression standardised residuals revealed one case to be an outlier. This case was removed. A model predicting 49% of the variance in performance (Adjusted R Square 0.49) was revealed. When common variance between the different tests was partialled out, only two contributed significantly to the SDSA predicted outcome. They were the Trail Making Test and the Stroop.

Table 2.10: Multiple Regression Analysis for the SDSA predictive equation

Cognitive Tests	B	Beta	Significance of t
Recognition Memory Test	0.04	0.08	$p=0.32$
Stroop	0.03	0.26	$p<0.01$
Trail Making	0.34	0.50	$p<0.001$
Cognitive Estimates	-0.05	-0.05	$p=0.49$
Constant	-5.14		$p<0.01$

2.5 Discussion

The subtests of the Stroke Drivers Screening Assessment (SDSA) were compared with a group of established cognitive assessments in an attempt to determine the construct validity of the SDSA. The findings make an important contribution to current hypotheses about the nature of cognitive abilities, which underpin SDSA performance, and to existing knowledge about the skills stroke patients need in order to drive safely.

Relationships between the SDSA subtests and additional cognitive tests were examined using Spearman's rho correlations. Correlations between the SDSA subtests suggest they touch upon measurement of shared abilities, which are important for driving. However, the absence of multicollinearity between all subtests suggests that in addition to shared measurement of some abilities such as attention, each test measures other abilities, which explain their unique contribution to overall SDSA performance.

The three predictive elements of the SDSA (Dot Cancellation, Compass Cards and Road Sign Recognition) were all associated with the Stroop and the Trail Making Test, suggesting the SDSA is predominantly a measure of executive abilities and attention. The highest correlation was that between Dot Cancellation-time and Trail Making (-0.57, $p<0.001$). This could be because both are affected by motor speed (Schear and Sato, 1989) and both tests are established measures of attention.

The Recognition Memory Test (RMT) was significantly related to the Compass Card test suggesting that visuoperceptual discrimination may be an important cognitive ability tapped by this, but no other subtest (Diesfeldt, 1990).

RMT was included as a measure of visual memory to determine whether the SDSA subtests, in particular Road Sign Recognition, were measuring aspects of visual memory. However, the Road Sign Recognition test, which was developed as a measure of knowledge for road signs and road hazards, did not correlate significantly with this known measure of visual memory. Whereas its counterpart the Verbal Description of Road Situations (VDRS) did. This relationship confirms that the VDRS does measure visual memory for road signs as was its intended purpose. However, the findings suggest that the RSRT measures abilities other than knowledge of road signs and road hazards. Higher correlation between RSRT and TMT than that between TMT and VDRS suggests RSRT may focus more on attentional abilities. Significant but not high correlation (0.40) between the RSRT and VDRS suggests that while they share measurement of some abilities, they are not identical. There was a significant difference in performance on the two tests ($z = -6.89$, $p<0.001$). Patients performed significantly better on VDRS than on RSRT, irrespective of the order of test administration. One explanation for this finding is that patients perform better when the unique emphasis on visuospatial discrimination is reduced. Apart from the emphasis on verbal skills in the VDRS, the main difference between the two versions seems to be that for the RSRT patients are required to devise and adopt a strategy for matching and checking the road situations with the road signs within a restricted time period (three minutes). By comparison in VDRS patients simply have to point to cards laid out before them. The two different approaches require different cognitive skills, which may explain the stronger associations between the RSRT with the Trail Making Test. It is possible that some of the difficulty in the RSRT is attributable to difficulty in interpreting information in the line drawings.

Cognitive Estimates was only significantly related to the Compass Card test. Cognitive Estimates (a measure of practical judgement using everyday knowledge) is thought to involve selecting and evaluating cognitive plans before responding (Luria, 1966), and good performance on the Compass Card test may require the ability to develop a response strategy. These findings would suggest that Compass Cards, like Cognitive Estimation, involves reasoning abilities dependent on frontal lobe function.

The VOSP cube analysis was significantly related to Compass Cards and the RSRT suggesting spatial analysis may be among the cognitive abilities tapped by these two SDSA subtests. The 2-D line drawings in Road Sign Recognition and photographs of model cars in the Compass Card test both represent vehicles travelling in different directions which patients must discriminate between. However, these correlations were not high (r_s 0.24 and r_s 0.21 respectively). The VOSP was also significantly correlated with the VDRS suggesting that this test also measures spatial abilities, but it is possible that this relationship is equally well explained by the fact that VOSP cube analysis is known to measure reasoning ability (Lezak, 1995).

Principal Components Analysis was carried out to explore relationships suggested by the correlational analysis further and to evaluate to what extent the SDSA subtests tap the same underlying contructs as other known cognitive tests. Two factors emerged from the analysis.

All of the SDSA subtests loaded heavily onto one factor. The known cognitive tests loading most heavily onto the first factor were the Trail Making Test and the Stroop. Speculation about what this factor may be is allowed by examining the nature of the established cognitive tests. The Stroop test was chosen as a measure of selective attention, frontal lobe function and high level concentration (Shum et al., 1990). The Stroop 'interference effect' (delay in naming the colour of a colour word when the word is printed in a different coloured ink) has been attributed to response conflict, failure of response inhibition and failure of selective attention (Dyer, 1973; Zajano and Gorman, 1986). Like the Stroop, the Trail Making Test is primarily a measure of attention. It also measures visual, conceptual and visuomotor tracking (Lezak, 1995). Excessive differences in time taken to complete the two parts is thought to indicate difficulties in complex conceptual tracking (Lezak, 1995). Focussed attention is required to follow number sequences (in part A) and divided and focussed attention are needed for Part B, where both number and letter sequences are attended to simultaneously. Grouping of the SDSA subtests with these two measures suggests the SDSA subtests also involve frontal lobe function (or executive abilities) and attention. This is fits with evidence indicating that the Dot Cancellation test (Bourdon Wiersma Stipple Test) is an established measure of visual search and focussed attention (Grewell, 1953) and is consistent with the suggestion that the Road Sign Recognition Test involves more than the ability to recognise road signs and road hazards. It also appears to tap these higher order skills.

Established tests loading on Factor two were the Cognitive Estimates and the Recognition Memory Test with cross loading to a lesser extent of the Stroop. The common element to these three tasks is that they all require verbal skills. The cross loading of the Compass Cards task suggests that this too requires verbal skills. These findings suggest the two factors, which underpin most of the performance on the SDSA are i) executive abilities and attention and ii) verbal skills. The findings of the Principal Components Analysis support those of the correlational analysis and of earlier findings.

To gain a clearer understanding of what is measured by each of the SDSA subtests and their contribution to the overall SDSA prediction, multiple linear regression analyses were carried out. The results suggested that those tests contributing most to the prediction of the SDSA subtests were tests of attention and executive abilities. For each of the subtests (Dot Cancellation-time, Compass Cards and RSRT) the Trail Making Test made a significant unique contribution to the prediction. For the RSRT and the Compass Cards, significant unique contributions were also made by the Stroop and by the Stroop and (to a lesser extent) the RMT respectively.

When the overall SDSA predicted outcome (Pass-Fail equation) was entered as a dependant variable, 49% of the variance in performance was predicted by the combination of test scores, but again only the Trail Making Test and the Stroop made significant unique contributions, which accounted for most of the prediction. This suggests that the SDSA calls upon the same abilities that are required for these two tests.

Overall the results suggest that the SDSA is primarily a measure of executive abilities and attention. The associations of all three sub tests to the Stroop and Trail Making Test suggest that all of the sub tests involve complex attentional abilities and high level cognitive functions associated with the frontal lobes.

2.5.1 Limitations of the study

The choice of tests was constrained by practical rather than theoretical considerations. The tests chosen were quick and easy to administer, required no formal training and could be easily transported and administered in patients' homes, therefore other more appropriate tests were not included.

There were ceiling effects on some of the tests due to the choice of measure. The VOSP was selected as a measure of visuospatial abilities. Unfortunately almost all patients scored the maximum on this test. Therefore a more sensitive measure would have been preferable.

The Cognitive Estimates test (Shallice and Evans, 1978) is now quite dated. The scoring guidelines are not sufficiently comprehensive and allow for subjective interpretation of answers, which could lead to scoring discrepancies.

This problem was highlighted by pilot work where no significant relationships were found between the Cognitive Estimates and other known measures of reasoning abilities (Melly, 1997).

Floor and ceiling effects may be attributable to the recruitment methods and the inclusion of patients with relatively mild cognitive problems. Most patients were recruited from the Derby Regional Mobility Centre where, following assessment, the majority were found to be safe to drive. Of those recruited from other sources, only those wishing to resume or who were already driving are likely to have volunteered. It is possible that these patients differed from the general stroke population in that they were less likely to have visual problems that would deter or prevent them from driving.

2.5.2 Relationship of the findings to driving

Given that driving represents a highly complex activity, which involves interplay between many different cognitive skills, the relationships between the SDSA subtests and known measures of attention, executive abilities, visuospatial skills and memory are not unexpected. The findings fit with research highlighting significant differences in these skills between brain damaged drivers found safe and unsafe to drive when tested on the public road (Duchek et al., 1998; Fitten et al., 1995; Fox et al., 1997; Lundqvist et al., 1997; 2000; Odenheimer et al., 1994).

2.5.2.1 Attention

The findings that the SDSA is predominantly a measure of attentional capacity and executive abilities is consistent with research relating driving to other established measures of these cognitive abilities. Among normal professional drivers, tests of information processing (selective attention, field dependence and complex reaction time) have been found to be significantly related to retrospective accident records (Kahneman et al., 1973; Mihal and Barrett, 1976). Among older drivers, selective attention has been found to be a major contributor to crashes involving older drivers and bike riders (Parasuraman and Nestor, 1993). In a study of healthy older drivers and those with mild Alzheimer's disease, Duchek et al., (1998) found measures of selective attention (computerised tests of visual search) were better able to differentiate safe versus unsafe drivers (as determined by road-testing) than dementia severity or traditional psychometric tests. This suggests that measures of selective attention are good predictors of driving in an older population, findings supported by Maratolli et al., (1998). Visual Search, like the Stroop and Dot Cancellation, is a measure of selective attention. This would explain why the SDSA subtests (which are strongly associated with the Stroop) are important predictors of driving ability. Similarly, a measure of visual attention the 'Useful Field of View' (UFOV) has been found to be a significant predictor of retrospective accidents (Ball and Owsley, 1991; Owsley et al., 1991; 1994). Owsley et al., (1998) found older drivers with a 40% reduction in the UFOV (which measures decline in visual sensory function, slowed visual processing speed and impaired visual attention skills) to be 2.2 times more likely to crash in the following three years (having accounted for age, sex, race, chronic medical condition, mental status and days driven per week). They attributed this association to difficulty in dividing attention under target durations. Owsley et al's (1998) findings suggest that measures of attention, in particular visual attention, are related to driving in older adults. However, in spite of the apparent usefulness of the UFOV, it has yet to be validated for brain damaged patients with less predictable patterns of cognitive and visual impairment, such as those who have suffered a stroke.

More traditional psychometric tests of divided attention and information processing speed have also been found predictive of road test failure among brain damaged drivers (Engum et al., 1988; 1989; 1990; Hunt et al, 1993; Lundqvist et al., 1997) and have the advantage of being easily transported and administered. However, selection and administration discrepancies have resulted in disparate research findings (Carr et al., 1998; Maratolli et al., 1998) and a miss-match of measures indicating relationships between cognitive abilities and driving but no definitive answers. The SDSA has an advantage in that it is a collection of measures, which both individually and in combination have established predictive validity for driving (Nouri et al., 1987, Nouri and Lincoln, 1992).

2.5.2.2 Visuospatial abilities

The results of this study suggest the Stroke Drivers Screening Assessment also measures visuospatial abilities. These are thought to relate to the ability to judge space and distance when monitoring oncoming cars and when overtaking (Doege et al., 1986) and to the ease with which drivers notice cues that lie ahead, such as traffic lights and road signs, and cues that lie in the periphery, such as cars pulling out, cyclists and pedestrians (Simms, 1985). Gurgold and Harden (1978) found the Frosting Test of Visual Perception could detect deficits in the ability to distinguish foreground information such as road signs and traffic lights from insignificant background.

Our findings are consistent with those of several authors who found significant relationships between on-road driving and tests of spatial abilities among brain damaged drivers (Mazer et al., 1998; Sivak et al., 1981). Brooke et al., (1992) found head-injured drivers with visuospatial deficits resulting in extreme slowness or distractibility failed on-road tests. More recently, Rizzo et al., (1997) found visuospatial impairments (reduction in UFOV and decreased perception of 3D structure from motion) to be strong predictors of crashes in patients with Alzheimer's disease, when tested on a high fidelity driving simulator.

2.5.2.3 Executive abilities

Skills of reasoning and judgement are thought to be important for car positioning, maintaining a safe distance, driving on roundabouts and journey planning (Alm, 1989; Hakamies-Blomqvist, 1996). They have also been attributed to shifting and adapting behaviour, such as adjusting speed to traffic conditions and to risk estimation (Brouwer and Withaar, 1997; Engum et al., 1988). Many authors have found significant relationships between tests of reasoning ability and on-road performance among brain damaged drivers (Brooke et al., 1992; Engum et al., 1988; 1989; 1990; Fattal, et al., 1998; Lambert and Engum, 1992; Lundqvist et al., 1997; Mazer et al., 1998; Nouri et al., 1987; Nouri and Lincoln, 1992).

2.5.2.4 Memory

Memory is thought to relate to the driver's ability to detect relevant information in different traffic situations i.e. knowing where, when and what to look for in different situations (Alm, 1989). The complex interaction between memory and visuoperceptual skills is thought to account for older drivers getting lost (Odenheimer, 1993) and may explain the relationship between a simple traffic sign recognition test and driving ability (Carr et al., 1998). However, as with the Road Sign Recognition Test, the involvement of higher order processes cannot be ruled out.

Irrespective of the predictive value of cognitive tests for crash history and crash risk, even where risks are no greater, there remains the problem of deciding who can drive and who should not. Over-stringent measures based on stereotypes of age-related cognitive decline will result in very low accident risk at high personal cost (such as loss of mobility, social isolation and depression- Barnes and Hoyle, 1995). A collection of cognitive tests of known relevance to and with predictive validity for driving is required. Tests should be diagnosis specific and preclude people fairly and accurately on the basis of their driving related cognitive impairments (McKenna, 1998). The Stroke Drivers Screening assessment is now an established test battery, which meets these criteria.

2.6 Summary

Although it is difficult to distinguish clearly between cognitive abilities required for specific driving tasks, research to date has indicated combinations of cognitive skills that are important for safe driving among people with brain