THE LEARNER DRIVER WITH SPINA BIFIDA AND HYDROCEPHALUS: CAN DRIVING ABILITY BE PREDICTED?

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ABSTRACT

The focus of this thesis is on the possible effects of cognitive deficit on the acquisition of driving skills in young people with spina bifida and hydrocephalus (SBH). The specific question addressed is whether success on the standard Driving Test can be predicted from performance on a battery of psychometric tests.

A review of the findings from studies on cognitive deficit and driving and the cognitive functioning of groups with SBH identified the areas of visual-perceptual skill, attention and memory as being of possible relevance in the assessment of suitability for driving. The second part of the thesis describes the development of a battery of tests to assess not only these skills, but also visual-motor ability, which, from results during the early stages was also thought to be of value in the assessment of skills for driving.

During development of the battery, the perceptual-cognitive tests chosen were completed by two series of SBH adults and by four matched groups of varying ability (able-bodied,

SBH, SB only and cerebral palsy). As the work progressed, it became clear that the prediction of driving success from cognitive tests was limited. However, the results of these studies and a small-scale study of 14 learner drivers during early tuition, highlighted efficient visual disembedding and memory skills as important for learning to drive. Of additional importance was the consistent finding that the reasons why a person did not become a driver had many causes, not necessarily related to cognitive functioning. In particular, financial circumstances, the availability of adapted cars and driving instructor techniques were often overiding factors in determining whether a person reached Driving Test standard or not.

No definitive answer, therefore, can be given to the specific question addressed in this thesis - can driving ability be predicted? It is clearly indicated, however, that although sound perceptual-cognitive skills are a prerequisite for learning to drive, they are not alone sufficient to predict driving success.

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CHAPTER ONE : OVERVIEW

The focus of this thesis is on the possible effects of cognitive deficit on the acquisition of driving skills in young people with spina bifida and hydrocephalus (SBH). The need for such a study arose in the late 1970s. There were two main reasons for this. First of all, advances in the early surgical treatment of those with spina bifida and hydrocephalus led to a marked increase in the percentage surviving to adolescence and adulthood. Secondly, it became much easier for people with disabilities to contemplate learning to drive. Until 1976, people with physical disabilities affecting mobility could only apply for a DHSS invalid three-wheeler vehicle (trike). When these were discontinued, however, they were replaced by Mobility Allowance, a cash benefit which could be used to buy or lease a car through the Government Motability Scheme. This benefit was available to all those "unable to walk or vitually unable to walk" and, of course, applied to most of those with spina bifida and hydrocephalus.

As a consequence of these two rather different sorts of development, the 1980s saw an increasingly large number of young people with spina bifida and hydrocephalus obtaining provisional licences and attempting to learn to drive. Some young people did, indeed, gain independence by this method, but many encountered unforeseen difficulties during the tuition period. Initially, the reasons for this were not well understood as most professionals were not aware of the complex problems associated with the conditions of spina bifida and hydrocephalus.

At a physical level, the problems of the prospective spina bifida driver were obvious. Most found it difficult (or even impossible) to use foot controls on the car. Others lacked adequate manual control to steer the car properly. Additional problems arose because of lack of stability in the trunk. Initially it seemed that what was required were simple mechanical car adaptations, which would enable those with physical difficulties to learn to drive more easily. However, even when specially fitted car adaptations were used to compensate for physical difficulties, many learners still seemed to find the task extraordinarily difficult. It was these failures that led to the suggestion that the cognitive deficits these young people suffered might be equally responsible for difficulties during the tuition period.

At the beginning of the 1980s, I was one of a multidisciplinary group of professionals, who participated in the setting up of Banstead Mobility Centre. The aim of this centre was to provide a comprehensive assessment of suitability for driving, ranging across medical, visual and physical criteria as well as assessment of cognitive skills. At that time, I also worked as a psychologist in an assessment centre for school leavers with physical difficulties. In the course of my work, the question of whether an individual was likely to be able to learn to drive was frequently raised. The school leavers assessment centre was attended primarily by those with spina bifida and hydrocephalus and it was towards this group that our attentions were initially focussed.

The studies on learner drivers with spina bifida and hydrocephalus, reported in this thesis, began at that time and formed part of my work at the Mobility Centre. In view of the longitudinal nature of the main study, the work has spanned a period of six years and as such has taken place against an ever increasing number of research studies addressing similar, but never identical, issues. In the early 1980s, for example, virtually no research findings were available to provide guidance on the most appropriate form of assessment for learner drivers with congenital cognitive impairment. As my own work on the development of assessment procedures has progressed, however, others have also shown an increasing interest in the area of cognitive deficit and driving and there is now a considerable body of knowledge on this topic. In evaluating the results of the studies presented here, therefore, it is important to consider them within their historical context.

Broadly speaking the introduction to the thesis can be divided into two parts. In the first, research on normal and brain-damaged adult drivers is considered. In the second, the condition of spina bifida and hydrocephalus is discussed.

There are several reasons for dealing with experienced, adult drivers. Firstly, it sets the scene for the different ways in which driving can be studied. The purpose of much research on driving is accident reduction. Many studies have therefore focussed on the identification of the factors which cause accidents. Other studies have approached the driving task through an analysis of the subtasks involved or by studying the cognitive processes likely to be important for driving in an experimental setting.

The review of the literature on driving in normal individuals highlights the importance of sound perceptual-cognitive skills for safe driving. In Chapter Two, by implication, the idea that the absence of some of these skills might lead to unsafe driving and accident involvement evolves. In Chapter Three what is known about brain damage and driving is reviewed. A change in focus from the use of psychometric tests to predict driving performance to the investigation of the relationship between particular tests and specific driving skills becomes evident.

As the main aim of this thesis is to assess whether those with congenital deficits can acquire driving skills, the next three chapters address themselves to the nature of the deficits associated with spina bifida and hydrocephalus. The first of these (Chapter Four) considers the medical, physical and neurological aspects of the condition. It is clear from the studies reviewed that those born with these disabilities may not only be disadvantaged by paralysis due to the spinal lesion, but also by intellectual deficit, due to hydrocephalic brain damage.

The second and third chapters on spina bifida and hydrocephalus, consider the intellectual deficits which might be associated with hydrocephalus. Longitudinal studies based in South Wales, Greater London and Sheffield are the source of many of the reports included in these chapters. Progressing from studies of global cognitive functioning, as assessed by IQ tests, Chapter Six considers the specific aspects of cognitive functioning which have been highlighted as likely to be important for driving. The studies fall into two broad categories - those which examine group profiles on tests such as the Wechsler Scales and those which use specific tests to assess selected aspects of cognitive functioning. The cognitive processes examined in detail are visual-perceptual motor deficit, memory and attention.

Following the review of relevant literature, the development of a perceptual-cognitive test battery for driving is described in Chapters Seven and Eight. As mentioned earlier, this began in 1981 soon after the setting up of Banstead Mobility Centre, with the aim of providing an objective measure of cognitive suitability for driving. The results from this and other studies, however, soon began to show that cognitive batteries alone were not sufficient to predict driving ability. The next three chapters, therefore, describe a specially designed course for teaching car control skills, simple road procedures, road signs and routes to a small group of young people with spina bifida and hydrocephalus. This course also allows an assessment of the contribution of non-cognitive variables to driving ability.

Following on from encouraging results from this focussed study, the final chapter proposes that not only should assessment for driving be broader based to take account of both cognitive and non-cognitive variables, but that more practical help needs to be provided for young people with disabilities who wish to learn to drive.

CHAPTER TWO : DRIVING BEHAVIOUR

Driving is a complex task involving a large number of perceptual, cognitive and motor subtasks. It is a difficult task to learn and usually requires formal teaching before the skill can be properly mastered. Most of the literature available on the process or acquisition of driving skills concerns the behaviour of experienced drivers or those who have returned to driving following traumatic injury. Although nondrivers with congenital cognitive deficit cannot easily be compared with experienced drivers (with or without brain damage) the review of the literature that follows will provide an overview of the driving task and factors which might affect safe driving behaviour.

There are three types of study which are informative in this regard. Firstly, studies examining the causes of accidents have provided strong support for the importance of efficient visual-perceptual and attentional skills for safe driving (Staughton and Storie, 1970; Treat et al, 1977). Secondly, studies of basic cognitive processes, often based on information processing models, have considered individual skills in detail eg. eye-movement control (Mourant and Rockwell, 1970) and reaction-time (Fergensen, 1971). The third type of study has used task analysis to identify the subtasks of driving at a behavioural level (eg. McKnight and Adams, 1971; Allen et al, 1971). Central to these task analytic studies is the assumption that identification of subtasks also allows identification of abstract skills which need to be trained.

The following section reviews in detail studies using these three approaches. This is followed by a description of more recent attempts in the Netherlands to marry abstract models of the driving task with behaviourally orientated models (eg. van Zomeren et al, 1987; van Wolffelaar et al, 1988).

1. ACCIDENT CAUSATION STUDIES

Studies by research institutions concerned with accident causation have as their main objective the ascertainment of which factors or combination of factors contribute most to accidents. The methodology they employ involves assessment at the scenes of accidents. Two major accident causation studies, one based at the UK Transport and Road Research Laboratory (TRRL) in Berkshire and the other at Indiana University (USA), will be reviewed.

One of the most important findings as far as this thesis is concerned was that 95% of accidents involved driver error. This figure was first reported by Staughton and Storie

(1970) in the TRRL study. This was in contrast to 9% of accidents related to vehicle faults and 28% to road or environmental design. Perhaps not surprisingly, these groups overlapped as in many accidents there was more than one contributory factor. The similarity between these figures and those later provided by Treat and his colleagues at Indiana University was striking (Treat et al, 1977). They identified the contributory causes of 13,568 accidents as follows:- human error (90.3%), vehicle fault (9.1%) and environmental error (33.8%).

Of particular interest in both studies was a further breakdown of types of driver error (Table 1). Although the method of division of the errors into each category was not always clearly explained, the errors listed in both studies seem to emphasise the role of adequate perceptual-cognitive skills and adherence to road procedures. Although direct comparison between the two studies is difficult due to the different categories used, the last four categories in the perceptual error section of the Indiana study - internal distraction, inattention, false assumption and improper lookout - seem to correspond quite closely with the TRRL categories of distraction/inattention, incorrect interpretation/misjudged speed and distance and "looked but failed to see". The percentage of errors in these four categories was approximately 50% in the Indiana study compared to 44% in the TRRL study.

TRRL STUDY		INDIANA STUDY	
DRIVING ERROR	% *	DRIVING ERROR	%
Lack of Skill	16.0	Improper Technique	9.0
Driver Impairment	33.0	Improper Manoeuvre	6.2
Manner of Execution	75.0	Poor Evasive Action	13.3
		Poor Defensive Driving	8.8
		Excessive Speed	16.9
		Overcompensation	6.0
PERCEPTUAL ERROR **		PERCEPTUAL ERROR	
Distraction/Inattention	22.0	Internal Distraction	9.0
Poor Interpretation	5.0	Inattention	15.0
Misjudged Speed/Distance	5.0	False Assumption	8.3
Looked/Failed to See	17.0	Improper Lookout	23.1

TABLE 1 : Percentage of driver errors contributing to accidents in TRRL and Indiana University Studies, with a breakdown of perceptual errors. * Categories are not mutually exclusive. ** expressed as a percentage of perceptual error alone (44%).

The main conclusion to be drawn from these two major accident causation studies is that driver error primarily comprised the perceptual-cognitive errors of inattention and ineffective search together with inappropriate decision making with basic car control skills playing a less crucial role.

2. STUDIES OF BASIC PROCESSES

2.1. STUDIES OF INDIVIDUAL SKILLS

As it is not always methodologically practical to investigate driver behaviours in "real-life" situations, techniques have been developed to study specific aspects of driving, or the cognitive aspects of driving, in more controlled situations. For example, in the two major studies mentioned above, "looked but failed to see" was noted as an important contributing factor in accidents. One of the earliest methods designed to measure the amount of attention a driver gives to different aspects of the road was the measurement of eye-movements in instrumented cars. Studies by Mourant and Rockwell (1970), showed that experienced drivers build up a rapid succession of eye fixations. In contrast, the inexperienced driver spent more time looking at fewer objects and in consequence missed pieces of information. For example, a novice driver might concentrate his attention on the traffic lights in the distance and yet fail to see a car pulling out immediately in front of him.

Irrespective of driving experience, it has also been postulated that individuals vary in their ability to distinguish essential from non-essential aspects of the environment. To study this, the concept of field dependency has been invoked. Field dependence is a term used to describe a person's ability to discern figures from a background. Studies have indicated that field independent drivers are quicker and more accurate in responding to emergency situations (Barrett and Thornton, 1968), are involved in fewer accidents (Williams, 1971), respond more quickly to road signs (Goodenough, 1976; Loo, 1978; Shoptaugh and Whitaker, 1984) and have a more efficient visual search system (Shinar, 1978).

Fergensen (1971) considered the interesting possibility that individual drivers drive to a limit determined by their information processing capacity and therefore safe driving must at least partly depend on the drivers evaluation of his ability to deal with complex situations. To evaluate this, he designed a simple but clear study to investigate the relationship between accident/violation record and reaction times on one and three choice reaction tests. It was seen that the no-accident group processed nearly twice as many "bits" of information per second as those with three or more accidents. The high violation/no-accident group processed information more quickly than the high violation/high accident group. The low violation group showed little change as a function of accident involvement.

Fergensen believed that the results of this study indicated a relationship between accidents and information overload.

That is, when the amount needed to be processed exceeds the capacity of the driver, a situation occurs that frequently leads to an accident. Individuals with a lowered capacity to process information will most frequently be overloaded and therefore will more frequently be involved in potentially hazardous situations.

2.2. INFORMATION PROCESSING APPROACHES

Many theoretical models have been constructed to study driver behaviour. Examples of such models include those considering the contribution of visual-perceptual information processing to vehicular guidance (Kramer and Rohr, 1982), the selection and analysis of information (Rumar, 1982) and risk and hazard perception (Summala, 1988).

Most of these models have been conceptualised within what is commonly known as the information processing approach. Perhaps the most important influence from which these models have grown was Broadbent's model of man as a limited capacity information processor (Broadbent, 1958). The underlying assumption in this and later models is that all the information available in the environment is not processed and that the component functions can be identified and studied. As an example of this approach, Figure 1 shows the model put forward by Rumar (1982) to depict the most important functions for the acquisition,

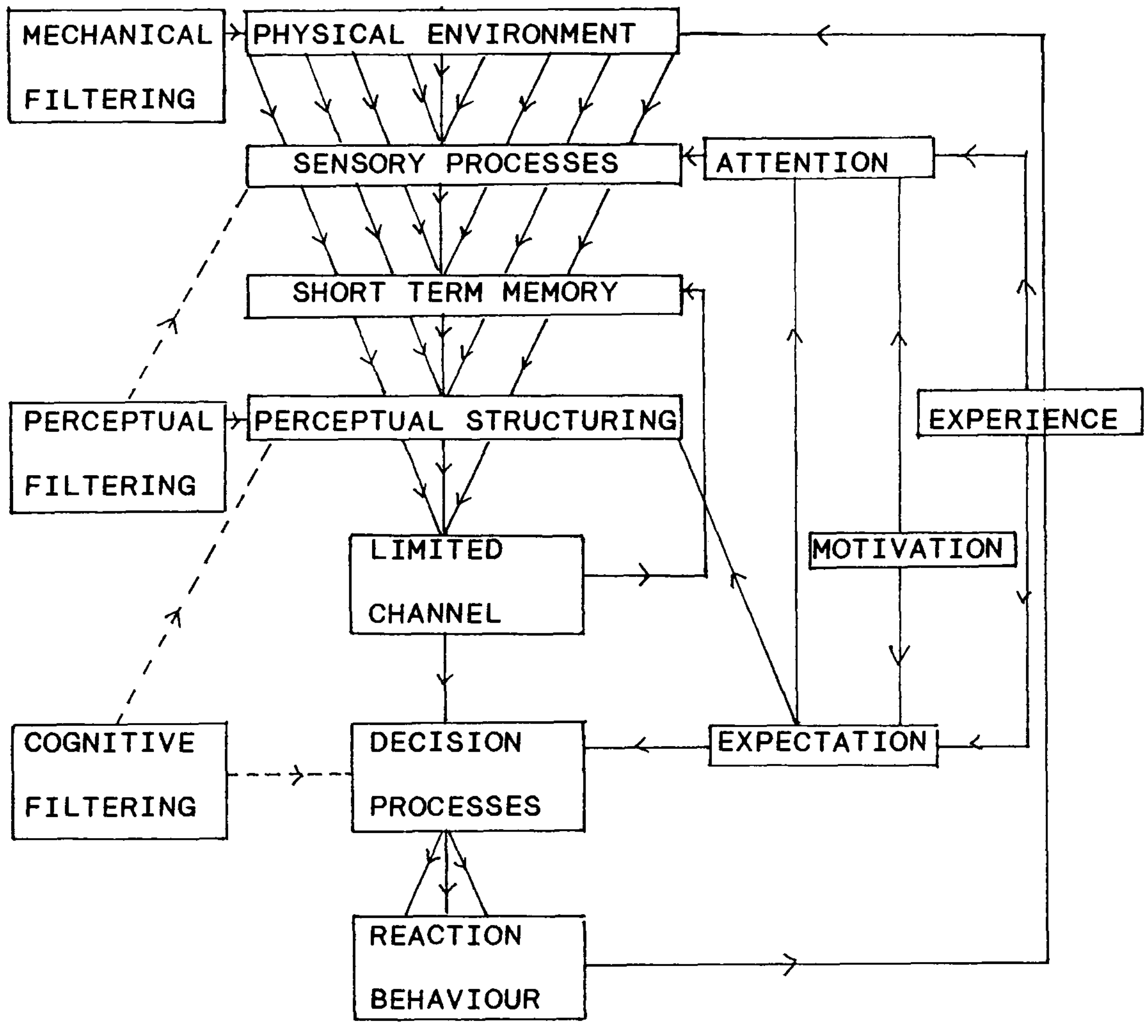


FIGURE 1 : Component functions of an information processing model proposed by Rumar (1982).

selection and processing of information during driving. A simple explanation of this model might go as follows. The outside world provides an excess of sensory information. For proper use it must be filtered and items selected for further analysis. As an example of filtering, features such as road signs, other vehicles and road markings can be considered relevant, whereas flowers and trees would be irrelevant. The level of attention and the perceptual skills of the driver will determine which items of information are processed. For example, a driver with poor visual search skills might not notice an overtaking car in the rearview mirror. This piece of information cannot be processed and the car's presence will not be taken into account when the driver himself wants to overtake.

A further important aspect to be considered is the integration of what is known from immediate input with what is remembered from previous experience. For instance, an experienced driver may be particularly vigilant when going through a shopping area because he remembers that in the past, pedestrians have stepped out unexpectedly from behind parked cars, or cars have pulled up to park without prior warning. On the basis, therefore, of the information received relating to the current road situation and in the light of past experience, a decision is made resulting in a motor response eg. the brake is applied when a pedestrian steps into the road. This explanation is, of course, rather simplistic, as new information is continually being presented, requiring a quick succession of decisions and actions. However the basic processes involved are the same.

2.3. TASK ANALYSIS

In contrast to approaches based on theoretical models of driving, task analysis operates at a purely behavioural level. The main objective is to specify the components of driving by successive breakdowns of tasks and subtasks. For example, a task such as overtaking might be subdivided as follows:- checking traffic signs and lane markings, observing the road ahead, deciding whether to pass, passing (or not).

In the main, the task analysis approach has been used in two types of research. Firstly it has been used in traffic policy making and secondly, to develop a set of instructional objectives for driver education. As an example of the first, the American researchers, Allen et al (1971) were commissioned to determine the information needs of drivers, with a view to improvement of road and information signs. To do this, they tape-recorded drivers' verbal observations on items such as road conditions, perceptions of traffic situations, physical movements and car responses eg. turning the ignition key starts the engine. Analysis of the data allowed the identification of subtasks, which were then categorised depending on the information needs associated with each subtask. For example one category, named "directional macro-performance" included all subtasks related to the driver finding his destination. The information needs might include indication of miles to the destination, the junction exit (from a motorway) and the road number. On the basis of data from their drivers, Allen and his colleagues were able not only to specify what information was required for each set of subtasks, but also at what stage in the trip this information could best be presented.

Another way of using task analysis was demonstrated by McKnight and Adams (1971), who were concerned with the development of a set of instructional objectives for driver education, again in the United States. These researchers began by identifying over 1000 specific driving behaviours. From a review of the traffic literature and transport system characteristics, the behaviours involved in different tasks (such as route planning, loading the car, overtaking and parking) were grouped together. Off-road tasks were classified under three headings - pre-trip, maintenance and legal responsibilities. On-road tasks were also divided into three categories - basic control tasks (eg. operation of the accelerator and brake), general driving tasks (eg. observation) and situational tasks (eg. overtaking). Further divisions were made within each task until, as earlier described in the overtaking example, each task was seen to be comprised of a chain of smaller subtasks.

Although McKnight and Adams made some attempt to link underlying cognitive processes to components of the driving task, Allen et al (1971) were more successful in developing an overall concept of the driving task. For example, their analysis involved hierarchies of subtasks, time scale and level of cognitive activity. A listing of subtasks, from low to high in the hierarchy, would include steering, speed control, responses to road situations, carrying out manoeuvres, route finding and trip planning. Performance of a subtask at any level would affect each subtask lower in the hierarchy. For example, steering is continuous throughout the driving task and is therefore involved in all higher level subtasks involving responding to road and traffic situations.

An important, additional aspect of this analysis is the concept of "load-shedding". Load-shedding describes the driver's division of attention between subtasks, depending on situational demands. For example, on a straight road a driver might attend to route finding, as lower order tasks such as steering can be performed semi-automatically. However, if a car pulls out in front of him, his attention must shift back to steering and he "sheds" the higher order task. The concept of "load-shedding" is also of particular relevance to the driving style of learner drivers who have not yet mastered lower order tasks. Attention for them must be focussed on tasks such as steering, to the detriment of higher order tasks such as observation and anticipation of traffic conditions.

More recently, workers in the Netherlands have developed an approach which seems to combine information processing and task analysis, explicitly to investigate the "higher cognitive levels" involved in driving (Ravenstein et al, 1982; van Zomeren et al, 1987; Korteling, 1988; van Wolffelaar et al, 1988). Within this Dutch model, the driving task is again divided into behaviour on three levels:-

(i) Strategic level ie. the planning of routes and trips.

(ii) Tactical level ie. preparatory actions whilst driving, such as slowing down at crossings.

(iii) Operational level ie. basic car control tasks, such as steering, observation and braking.

Variables such as situation complexity, attentional demands and time pressures are shown as affecting driving performance. Within this model, the anticipation of events or decisions made at the strategic or tactical level can affect how much time is allowed for moment to moment actions. For example, slowing down in a busy shopping area allows more time if a person unexpectedly steps into the road. Choosing a different route to avoid the shopping area completely would in addition lessen the pressures of driving. Individual differences in dealing with the time pressures of driving, particularly forward planning and anticipation skills, form an integral part of this Dutch model. This approach has proved very valuable in considering differences in the cognitive strategies of normal, elderly and brain-damaged drivers and will be discussed in detail in the next chapter on "Cognitive Deficit and Driving".

3. SUMMARY

Although brief and highly selective, in the section above I have attempted to emphasise the importance of sound perceptual-cognitive skills for safe driving. By implication the absence of some of these skills might be thought to lead to hazardous driving or indeed accident involvement. Although there is some indication that driving experience may improve driver efficiency, particularly in the ability to search the environment effectively, an individual's overall information processing capacity may be a major determinant of his ability to deal with complex traffic situations. This suggests that those with cognitive impairments, whether due to congenital or traumatic damage, may process information less competently and may therefore be involved in accidents more frequently. The following chapter, therefore, reviews the literature relating to cognitive deficit and driving.

CHAPTER THREE : COGNITIVE DEFICIT AND DRIVING

Difficulty in executing the perceptual and cognitive skills of driving can be observed both in normal and brain-damaged individuals. For example, driving skills frequently deteriorate with the normal ageing process. However, in those who have sustained brain damage, the effects of cognitive deficit may be more marked. Those who have suffered a stroke or head injury, with often specific localisation of damage, show quite different deficits to those who are affected by a disease process, such as multiple sclerosis, or a viral infection such as encephalitis. When a return to driving is being considered there is also a need to differentiate between progressive or non-progressive disorders and also those in which spontaneous (although normally partial) recovery may be possible.

Perhaps, not surprisingly, those who have had strokes or who have sustained head injuries are the groups studied in greatest detail. For these groups, assessment for driving is a real-life exercise likely to influence future prospects relating to independence, social life and work opportunities. The majority of such studies, therefore, have been concerned with a return to driving and not with the acquisition of driving skills. Although the results of such studies are not directly relevant to the congenitally cognitively impaired driver, a review of the literature will provide the background to the development of the test battery used in this thesis.

1. ASSESSMENT FOR DRIVING

Over the last twenty years, a clear development in studies of brain-damaged adults and driving can be discerned. To begin with, the main focus was on the selection of appropriate psychometric tests which might predict safe driving performance (eg. Sullivan et al, 1975; Golper et al, 1980). At this stage, the outcome measure was often simply whether a person returned to driving or not. The majority of these studies were reports from centres concerned with rehabilitation programmes and, as such, often lacked sound methodology and sample selection. Alternatively as the field developed, studies paid more attention to the relationship between particular tests and specific driving skills. Although a few of these more rigorous studies were reported by rehabilitation centres (eg. Jones et al, 1983), most took place at research institutions (eg. Sivak et al, 1981; Nouri et al, 1987; van Zomeren, 1988). The results of studies from both rehabilitation programmes and research institutes are discussed below.

1.1. STUDIES IN REHABILITATION CENTRES

The earliest published studies on driving and brain damage are very limited. All that can be said of them is that they serve to illustrate some of the cognitive deficits exhibited by adult patients who require rehabilitation following disability. For example, Bardach (1971) described a group of 49 stroke drivers who participated in a driver training programme. She reported that those with damage to the left side of the brain were more successful during training than those with damage to the right side of the brain ie. the part primarily concerned with the processing of perceptual-spatial information. The perceptual-cognitive difficulties noted consisted of "inadequate scanning of the environment with consequent poor planning, inability to shift according to the changing demands of the driving task, distractibility, poor judgement and confusion". In addition, she noted that perceptual-motor difficulties affecting left-right orientation and the use of space were in evidence. Unfortunately however, this work gave no details of the assessment procedures used and a rather poor description of the sample.

More details on assessment procedures were provided by Sullivan et al (1975) and Golper et al (1980). Through a systematic evaluation of physical, perceptual, language, visual, reaction-time and attitude measures, Sullivan and his team believed that they might be able to predict whether a person who had had a stroke was likely to be a safe driver - "without the need for actual road testing". As shown in Table 2(a), the perceptual-cognitive tests used to assess the skills thought to be important for driving, are consistent with those mentioned in the research on driving behaviour in "normal" drivers. However no validation of these tests was attempted by in-car tests.

In contrast, Golper et al, in a study with aphasic stroke drivers, considered the rehabilitation team's view on suitability to drive with the view of the driver and the results of perceptual-cognitive tests (Table 2(b)). They found that although there was good agreement between the assessment recommendation (based on physical, medical, visual and cognitive assessment) and the driver's own evaluation of his abilities, the results of the test battery were not predictive of whether driving was resumed. However, no check on driving performance was made for those who did return to driving.

Although the assessment procedures used by Sullivan and Golper represent an advance on Bardach's more subjective evaluation, neither study actually assessed on-road driving. If an outcome measure was considered it was simply whether driving was resumed or not. It was not until 1983 that studies appeared which reported details of

DRIVING EVALUATION FOLLOWING A STROKE
Spatial Relationships: Block Design
Figure-Ground Discrim: S.Calif. V.Perception Test
Integration of Body Parts: eg. Draw a Man
Visual Memory: Benton Visual Retention Test
Auditory Memory: Digit Span, Mental Arithmetic
Picture Interpretation
Reading Comprehension
Reaction-Time
General Attitude

TABLE 2(a): Perceptual-cognitive tests used by Sullivan et al (1975).

DRIVING EVALUATION FOLLOWING A STROKE
Motor Sequencing: Visual Efficiency Scale (VES)
Matching/Identification of Shapes and Form: VES
Visual-Spatial Relationships
Figure-Ground Perception
Left-Right Discrimination
Relating Parts to Wholes
Body Image
Reading Comprehension
Reaction-Time

TABLE 2(b): Perceptual-cognitive tests used by by Golper et al (1980).

assessment procedures that were both clinical and practical (eg. Quigley and DeLisa, 1983; Jones et al, 1983).

Quigley and DeLisa (1983) reported that, following physical and visual checks, stroke patients in a Washington Rehabilitation Centre completed a battery of cognitive tests. Twenty-three of the patients had left-sided brain damage and 27 right-sided damage. The previous driving experience of the group was varied, with some being nondrivers. The tests used included parts of the Bender-Gestalt Battery (immediate memory, design copying, drawing from memory and Trail Making Tests) and the Wechsler Adult Intelligence Scale (WAIS)(Digit Span and Digit Symbol subtests). The cognitive skills that Quigley and DeLisa believed they were testing in this battery included visual attention, spatial organisation, visual memory and learning, abstract thinking and problem solving.

Various differences in cognitive functioning between the groups with left and right-sided damage were noted. Not surprisingly those with right-sided damage found particular difficulty on the visual-perceptual and spatial tests. However both groups were impaired on the Digit Span and Digit Symbol Tests. When Quigley and DeLisa suggested that these tests "pinpont deficits in the ability to follow sequences and demonstrate flexibility in thinking", they further suggested that "deficits in these skills may result in slower perception and reaction-time when the driver is presented with novel training situations".

The 50 patients then followed a driver training programme, followed by the State Driving Test. It was found that 74% of those with left-sided damage passed the test compared to 52% with right-sided damage. However, as in the previously reported studies, no attempt was made to predict Driving Test success from cognitive test scores on an individual basis.

One of the first studies to consider the notion of prediction directly was conducted by clinicians in a New Zealand hospital (Jones et al, 1983). Jones et al very carefully considered the relationship between the results of reaction-time and tracking tasks and on-road tests. They reported on 300 patients aged 15-86 years (mean age:44years) assessed for driving over a five year period. Two hundred and sixty-one (89%) had some form of brain damage, over half having had a stroke or head injury. Assessment procedures included visual checks, computer administered reaction-time and tracking tasks and on-road tests. The on-road test progressed from driving in quiet areas, to assess basic driving skills, to driving along busier routes to allow evaluation of "responses in cognitive and perceptually demanding situations, knowledge of road rules, and general attitude". Patients were assigned to one of three main groups (pass, borderline, fail) according to overall assessment findings, but based primarily, according to the authors, on on-road driving performance.

Of particular interest in this study was the finding that there were significant differences in the number of errors on the tracking task (maintaining an arrow on sine and random waves on a screen) between the three groups. The mean tracking error score increased from 13.3 (pass) to 18.3 (borderline) to 29.9 (fail) across assessment ratings compared to 9.3 for a control group of 34 normal subjects ($p<.001$). The authors considered that the tracking task primarily assessed difficulties in co-ordination, motor planning, learning and concentration. In contrast, reaction-times were not found to be associated with assessment ratings. It was also reported that those with slow measured reaction-times could often compensate by cautious driving on the road; and those who performed well on off-road tests could prove generally erratic or emotionally unstable on the road.

An interesting extension to this study, included in the same paper, is a report on 38 of the 300 patients who were referred for driver training sessions following a "borderline" assessment rating. These 38 people, 6 with no driving experience, were considered to require "intensive on-road training to overcome severe disabilities" before a final assessment recommendation could be made. The diagnostic categories of the 38 were 9 head injuries, 9 with cerebral palsy, 9 strokes, 5 unspecified brain damage and 5 with musculoskeletal deformities. The number of training sessions per person ranged from 1-30, those requiring more sessions being new drivers with cerebral palsy. Twenty-three of the group successfully completed the training programme to become drivers, success rates being lower for those with head injuries or cerebral palsy. The authors emphasised that the "unproductive training" of the 15 patients who did not reach acceptable levels of driving, "reflects deficits in our program as well as difficulties in predicting the outcome of unlicensed patients with severe disabilities".

The difficulty of predicting driving potential was again considered by Jones , co-authored in this later paper by Croft (Croft and Jones, 1987). The study is of particular relevance to this thesis as the group assessed were all nondrivers and included 103 individuals with brain damage, 70 having a congenital disability and 33 a traumatic injury. For the total group of 151, the mean age was 22.9 years (range:15-76 years). The assessment procedure was the same as for the drivers described above, excluding the road test. Assuming medical eligibility to apply for a licence, only if performance on the tracking and reaction-time tests were satisfactory was a road test given.

The results were as follows. Fifty-seven percent of those assessed were given pass or borderline pass recommendations, 38% failed and 5% did not complete the assessment. Failure was often due to a combination of marginal results although tracking performance was again reported as "the most effective single pass/fail indicator where brain damage was suspected or confirmed". The authors also reported that driving licences were eventually gained by 48 of the 86 recommended to drive and none of those who failed (although only one was known to have subsequently arranged tuition). It is unfortunate that details of the disabilities of those comprising the pass and fail groups were not given as this represents the only published study of primarily young nondrivers with congenital cognitive impairments.

The retrospective nature of all the studies reported as part of the rehabilitation process makes interpretation of test results difficult. In addition, in some of the studies reported, although both clinical and in-car tests were included in assessment procedures, there was little attempt to evaluate the contribution of specific tests to driving performance. In general, however there seems to be a consensus of agreement that assessment for driving should be made on the basis of cognitive tests supplemented by in-car tests.

1.2. STUDIES IN RESEARCH INSTITUTES

By their very nature, rehabilitation centres are not set up to use well designed research procedures. Over the last decade research institutions have also begun to contribute to the investigation of the nature of the cognitive deficits associated with brain damage and their relationship with driving (eg. Thompson et al, 1980; Wilson and Smith, 1983; Nouri et al, 1987; Korteling, 1988; van Zomeren et al, 1988). The studies from these centres are in general well designed and provide adequate details of the groups studied, although in some, a lack of medical knowledge is evident. For example Wilson and Smith (1983) included a head-injured person in their stroke group and Schweitzer et al (1988) a person with spina bifida amongst their spinal injuries. It is also the case that the majority of studies used small groups of subjects, necessitating careful interpretation of results.

Table 3 provides a summary of 13 studies completed by researchers as opposed to clinicians. One of the earliest of these reports came from the General Motors Research Laboratories, Michigan, and was initiated as a result of interest in developing a simulator for use with disabled drivers (Thompson et al, 1980). Although only 4 subjects were assessed in this laboratory based study, it is of interest that the two brain-damaged males were young

STUDY AND SUBJECTS	TESTS USED
Thompson et al (1980) 2 CP, 2 AB Teenage males, non-drivers	1. Lateral position control 2. Critical tracking
Boydstun et al (1980) 5 males, 5 females (CP,SB,FA) 18-25 yrs (1 driver, 7 L-drivers, 2 non-drivers) . 10 AB drivers.	1. Lateral position control 2. Road test
Sivak et al (1981) 17 males, 6 females (CVA,HI,CP)18-69 yrs. 8 SI , 10 AB (19-45 yrs). Drivers.	1. Cognitive battery 2. Closed course manoeuvres 3. Road test
Ravestein et al (1982) 8 males, 1 female HI (20-30 yrs) 9 AB drivers	1. WAIS subtests 2. Trail Making Test 3. Letter Cancellation 4. Reaction-Time 5. Closed course manoeuvres

TABLE 3 : Studies examining the relationship between brain damage and driving (cond).

STUDY AND SUBJECTS	TESTS USED
Wilson and Smith (1983) 10 CVA, 1 HI drivers. 11 AB (46-65 yrs), 8 AB (18-26 yrs).	1. Closed course manoeuvres 2. Road test
Sivak et al (1984) 3 HI, 1 LCVA, 4 RCVA (19-67 yrs) Drivers	1. WAIS subtests 2. Symbol Digit 3. Trail Making 4. Letter Cancellation 5. Perceptual training 6. Road test
Stokx and Gaillard (1986) 9 HI, 9 AB (20-30 yrs) Drivers	1. Reaction-Time 2. Closed course manoeuvres
Nouri et al (1987) 23 RCVA, 16 LCVA (33-75 yrs) Drivers	1. Cognitive battery 2. Road test
Korteling (1988) 10 HI, 10 AB male drivers (mean age :30 yrs), 10 AB drivers (mean age: 66yrs)	1. Reaction-Time 2. Duration Categor-isation Task 3. Road test

TABLE 3 : Studies examining the relationship between brain damage and driving (cond).

STUDY AND SUBJECTS	TESTS USED
Van Zomeren et al (1988) 9 HI men, 9 AB drivers (mean age:28 yrs)	1. Cognitive battery 2. Closed course manoeuvres 3. Road test
Van Wolffelaar et al (1988) 17 HI males, 3 HI females (25-52yrs) Drivers. 15 AB drivers (27-41 yrs)	1. Reaction-Time 2. Minnesota Test 3. Trail Making 4. WAIS Picture Completion 5. Embedded Figures Test 6. Tower of Hanoi 7. Tracking task 8. Traffic merging task 9. Road test
Schweitzer et al (1988) (a) 7 HI, 7 AB drivers	1. Reaction-time 2. Visual search 3. Tracking tasks

TABLE 3 : Studies examining the relationship between brain damage and driving (cond).

STUDY AND SUBJECTS	TESTS USED
Schweitzer et al (1988) (b) 10 HI (mean age:29yrs), 6 SI, 1 SB (mean age:27yrs), 8 AB (mean age: 19yrs)	1. Cognitive battery 2. Reaction-time 3. Visual search 4. Tracking tasks 5. Driver Performance Test 6. Closed course manoeuvres

TABLE 3 : Studies examining the relationship between brain damage and driving. AB=Able-Bodied CP=Cerebral Palsy CVA=Cerebrovascular Accident FA=Friederich's Ataxia HI=Head Injury LCVA=Left CVA RCVA=Right CVA SB=Spina Bifida

nondrivers with congenital cognitive impairment associated with cerebral palsy (CP). The two disabled and two control subjects completed driving simulator tasks to assess lateral position control and tracking. The authors discussed the results of each individual as no statistical comparisons would have been valid for the small number of subjects. In general a greater variability was seen in the performance of both of the CP males in their ability to maintain lateral position in the face of speed and wind strength changes. In addition one of the CP subjects also found other aspects of the task difficult.

The University of Michigan followed this initiative by designing a study which considered the predictive validity of performance on a driving simulator for driving skills (Boydstun et al, 1980). Ten young people (18-25 years) with brain damage affecting perceptual functioning (CP, Spina Bifida and Friederich's Ataxia) and 10 able-bodied controls participated. All of the able-bodied group were drivers and 8 of the brain-damaged group had had previous driving experience. The tests involved lateral position tasks on a computer simulation of a straight two lane road, with random presentation of wind gusts. A road test in normal traffic over a 10 mile suburban course was also completed. This was supervised by a driving instructor and evaluated by an in-car observer. The results were as follows.

Two of the brain-damaged subjects did not complete the road test so results were presented for 8 in each group only. The correlation between the road test error scores and lateral position error scores was surprisingly high ($r=.88$; $p<.001$). However, the results of this study were presented in a rather unusual way, as differences between the two groups were not reported. The high correlation could therefore purely be a reflection of the bimodal distribution of the scores.

Although the impetus for assessment using a driving simulator came from the University of Michigan, for some unknown reason, a later series of studies in the 1980s used the more traditional approach of a battery of cognitive tests in conjunction with in-car assessment. A new departure, however, was the differentiation between driving performance on closed course manoeuvres (ie. traffic free) and in-traffic situations.

The first of these studies (Sivak et al, 1981) investigated the correlation between perceptual-cognitive test scores and driving performance in a group of 23 drivers with brain damage of mixed aetiology (13 strokes, 7 head-injured, 3 with cerebral palsy), 8 people with spinal injuries and 10 able-bodied people. All subjects completed a battery of 12 tests, which Sivak described as assessing all aspects of cognitive functioning, but primarily those involving perceptual skills (Table 4). In-car tests both on and off the road were also completed. The off-road tests took place on a closed course and involved tracking, figure 8 and stopping at a specified point with the eyes closed. The on-road test covered a 17 kilometre route in normal traffic conditions, supervised by a driver educator. Performance was also evaluated by an observer in the car, who rated 144 pre-determined actions on a 2 point scale.

Not unexpectedly, findings indicated that as a group, subjects with brain damage performed significantly worse

TEST	SKILLS ASSESSED
Ayres Space Test	Visual-spatial ability
Motor Free Visual Perception Test	Visual discrimination
WAIS Picture Completion	Perceptual discrimination
Rod and Frame Test	Field dependency
Southern California Figure-Ground Test	Figure-ground discrimination
Symbol Digit Modalities	Attention
WAIS Picture Arrangement	Non-verbal reasoning ability
Porteus Maze	Planning and foresight
Abstract Reasoning Test	Abstract reasoning
WAIS Arithmetic	Immediate memory/concentration
WAIS Digit Span	Auditory attention span
Vocabulary	Verbal understanding
Choice Reaction-Time	Perceptual-motor co-ordination

TABLE 4 : Cognitive test battery used by Sivak et al (1981)

than able-bodied subjects on many of the perceptual and cognitive tests. A significant finding, not considered in other studies, was that different tests were predictive of overall driving performance for those with and without brain damage. In this study, the tests which correlated most highly with driving performance for those with brain damage were the Picture Completion (r=.72) and Picture

Arrangement (r=.46) Tests. For those without brain damage, the most predictive tests were the Porteus Maze (r=.77), Rod and Frame (r=.62), Abstract Reasoning (r=.55) and the Ayres Space (r=.52) Tests.

In addition, Sivak et al found that "persons with brain damage, as a group, performed significantly worse than the able-bodied on several measures of both closed course and open road driving". For the group without brain damage some measures from the closed course driving correlated with a Composite Driving Index (mean of the percent correct for each category of driving actions). However for the brain-damaged group no such relationship was found. Sivak considered that this finding might suggest that the driving task is different for the two groups and that "traditional closed-course driving manoeuvres might not tap the driving related skills of persons with brain damage".

Sivak and his colleagues (Sivak et al, 1984, 1984a) followed this study with two small-scale studies which considered the effect of cognitive retraining on driving performance. Although not within the scope of this thesis, it is interesting to note that there were some indications that retraining not only improved the tested perceptual skills of the small group of 8 drivers, but was also considered to improve driving performance.

Two further studies, planned as research projects to investigate returning to driving after a stroke are of particular interest. The first study by Wilson and Smith (1983) serves to highlight the specific in-car difficulties of some stroke drivers, although used no other tests to assess residual deficit. In contrast, the second study (Nouri et al, 1987) presented a detailed report on the relationship between cognitive test scores and driving performance.

Wilson and Smith (1983) reported on the driving performance of 10 strokes and 1 head-injured patient (Stroke Group), 11 drivers aged 45-65 years and 11 drivers aged 18-26 years (Control Groups). The 24 kilometre drive consisted of city driving, motorway and cross country driving together with off-road manoeuvres. In general, the results highlighted the poor standard of the stroke drivers compared to the control drivers during both on-road and off-road driving. The stroke drivers "exhibited special difficulty in entering and leaving a motorway and in handling traffic in roundabouts". In the off-road situation they "seemed to be relatively unaware of potentially interacting vehicles, exhibited considerable difficulty in doing two things at once in an emergency, and had some difficulty in tasks involving complex reversing and placing their car on the left". These results, therefore, seem discouraging for the competence of those returning to driving after a stroke, although shed no further light on how driving ability might be predicted.

In 1987, Nouri et al presented details on both the driving performance and cognitive test results of a group of 39 stroke patients. The subjects were 36 men and 3 women aged 33-75 years (mean age:59 years), 6 weeks to 4 years post-stroke. Twenty-three had right-sided brain damage and 16 left-sided damage. The cognitive battery listed in Table 5 was considered to assess skills related to spatial ability, visual inattention, visual memory, choice reaction-time, reasoning ability, hand-eye co-ordination, auditory comprehension and motor sequencing. In addition road sign and hazard recognition tests and visual acuity were assessed.

Following cognitive assessment, each driver completed a road test with a qualified instructor over a set route including side and main roads, roundabouts and major junctions. Drivers were rated on 23 manoeuvres and road procedures by the instructor and on 49 similar items by an observer in the car. The instructor and observer independently assessed each driver to a pass, borderline or fail category on the basis of these ratings. Using the cognitive assessment as the dependent variable, the scores on each test were compared between the three categories of the instructor and observer ratings separately. There was

TEST	SKILLS ASSESSED
Cube Copy Test *	Spatial ability
Dot Cancellation *	Visual inattention and concentration
Rey Figure Copy and Recall *	Visual inattention,spatial abilities and memory
Four Choice Reaction-Time *	Choice reaction-time
What's in the Square?	Reasoning ability
What Else is in the Square? *	Complex reasoning ability
Pursuit Rotor *	Hand-eye co-ordination
Token Test Part V	Auditory comprehension
Hand Sequencing Task	Motor sequencing
Recognition Memory Test-Faces	Visual memory
Road Sign Recognition Test *	Visual comprehension
Hazard Recognition Task *	Visual recall

TABLE 5 : Cognitive assessment battery used by Nouri et al (1987), showing tests* which differentiated between levels of driving competence.

considerable agreement between both sets of scores, 9 of 23 measures showing significant differences between grading categories. For the driving instructor ratings these were Cube Copy, Dot Cancellation Time and Omissions, Rey Figure Recall, What Else is in the Square?, Pursuit Rotor at 10rpm and 15rpm, Road Sign Recognition and Hazard Recognition.

For the observer ratings Pursuit Rotor at 15rpm was not significant but mean Choice Reaction-Time was significant at the .001 level.

Discriminant Function Analysis indicated that the combination of weighted test scores most likely to predict driving performance was Dot Cancellation, Rey Figure, What Else is in the Square?, Pursuit Rotor, Token Test, Recognition Memory Test, Cube Copy and Hazard Recognition, together with the results of visual acuity and field tests. Using this formula, 37 of the 39 (94%) drivers were correctly classified as having passed or failed the road test. These impressive results suggest that the driving performance of stroke patients can be predicted using cognitive tests.

Unfortunately, the results from other studies have not been as conclusive. During the 1980s researchers in the Netherlands have published an interesting series of studies relating to head injury and driving skills. The main centres are at the Institute of Perception, Soesterberg, and the Traffic Research Centre at the University of Groningen.

At the Institute of Perception, Ravestein et al (1982) used a selection of clinical and off-road driving tests to assess the cognitive and driving skills of a group of 10 head-injured subjects aged 20-30 years. A control group was also studied. The cognitive tests included WAIS Picture Completion, Picture Arrangement and Digit Symbol Tests, Trail Making Test and the Letter Cancellation Test following Sivak et al (1981). Results showed that although the head-injured group were generally slower and less accurate over all tasks, no selective effects of brain damage were in evidence. Neither was the driving of the head-injured group significantly different to the control group on off-road or Highway Code measures.

A continuation of this work considered the reaction-times of a variable group of 9 head-injured men (20-30 years) at least two years post-accident (Stokx and Gaillard, 1986). The purposes of the study were to determine (a) whether the stages of response selection and motor preparation in the reaction-time process were specifically affected by head injury and (b) whether reaction-time performance was predictive of car driving. A series of 4 choice reaction-time tasks were presented to investigate stages in the reaction-time process. These tasks were designed to assess the effect of stimulus response compatibility, stimulus degradation, memory set size and distraction on reaction-time. Overall the performance of the control and head-injured did not differ significantly in quality although the reaction-times of the head-injured were longer.

The nine subjects who completed the experimental task on stimulus response compatibility also completed 4 in-car tests assessing ability to change gear, brake and drive a slalom course with and without a secondary task (responding to flashing lights on the side of the car). Again the only differences between groups were on the times taken to complete the tasks rather than on accuracy of performance. Correlations were calculated between driving tasks and the reaction-time tasks. A correlation of .69 was found between the slalom task and reaction-time for those with head injury only. Despite the small numbers involved, the authors considered that reaction-time may have predictive validity for driving ability in those with head injury.

Korteling's work at the same centre investigated differences between 10 head-injured males (mean age:30 years), 10 matched controls and ten elderly males (mean age:66 years) on laboratory (choice reaction-time, duration categorisation time) and in-car reaction-time tests (duration categorisation time and platoon following) (Korteling, 1988). The Duration Categorisation Time task was designed to simulate driver decisions at an intersection with traffic lights. It involved pressing one of two response buttons to indicate the duration of a green light. Results indicated that although elderly males were slower on the reaction-time test, they were faster than the head-injured group on the Duration Categorisation Task.

The brain-damaged group was also slower responding with increased task load (finer discriminations) and slower responding to the lead car in the platoon following exercise.

Similar work on head injury and driving has developed from research on attention at the University of Groningen. Van Zomeren et al recently reported a small-scale study of 9 head-injured patients and 9 controls (van Zomeren et al, 1988). The mean time from head injury was 6.5 years but there was a wide range of severity of the original injury and driving experience pre- and post-injury. The control group was carefully matched on socio-economic background, IQ (head injured:102.7; control:105.3), age (28.4 years) and driving experience. All 18 subjects were interviewed and completed the test battery shown in Table 6. In-car assessment comprised a steering test of lateral position control and a one hour drive rated as an Advanced Drivers Test by a regular examiner.

The results demonstrated an impressive difference between the groups. The cognitive tests showed "clear residual deficits in all functional categories" in the head-injured group; lateral position control was "significantly weaker" and five-head injured drivers were rated as "insufficient" on the Advanced Drivers Test. Interestingly however, no

TEST	SKILLS ASSESSED
15 Words Test Benton Visual Retention Tachistoscope Test	Memory
WAIS Picture Completion WAIS Picture Arrangement Trail Making Letter Cancellation Task	Visual perception and search
Letter Cancellation Task Stroop Colour Test WAIS Digit Symbol	Attention
Visual 4 Choice Reaction Minnesota Rate of Manipulation Finger Tapping	Motor functions

TABLE 6 : Cognitive battery used by van Zomeren et al (1988) with 9 head-injured and 9 control drivers.

correlations were found between test scores and in-traffic driving; nor between lateral position control and in-traffic driving. However the steering task was associated with poor scores on the Visual Retention Test, Trail Making A and the Minnesota Rate of Manipulation Test. The authors pointed out that all these tests have a strong visual-motor component, in common with the car position test.

These authors interpreted their findings within the hierarchical model of driving, described in Chapter Two on Driving Behaviour. A summary of the main features of this model is given before the findings are further discussed. This model subdivides driving tasks into behaviour on three levels - the strategic level, the tactical level and the operational level. On the strategic level, choices and decisions are made concerning routes, timing etc. There are usually no time pressures for these primarily pre-trip tasks. On the tactical level, preparatory actions are taken whilst driving eg. slowing down when approaching a busy shopping area. Some time pressure may be present. The operational level is comprised of moment to moment actions whilst driving. There is constant pressure at this level, as there is only limited time for responding and reacting to situations as they arise.

When discussing the test results and driving performance in the study above, van Zomeren and his colleagues put forward the view that the test battery assessed function relevant to the operational level eg. visual search, eye-hand co-ordination. This would account for correlations between certain tests and lateral position control, an operational task. They suggested that the head-injured drivers who were considered safe had learnt strategies to compensate for deficits. Within this hierarchical model, decisions to determine pressure were being made at the strategic and tactical level. It is possible that those drivers with insight were also those with most driving experience, as further analysis indicated that the most experienced drivers demonstrated fewer errors of "perception and insight".

Van Wolffelaar et al (1988) reported what appears to be an extension of van Zomeren's work. In their study, 20 head-injured drivers and 15 matched controls completed a test battery aimed to assess (a) "lower" cognitive functions such as reaction-time, eye-hand co-ordination, visual discrimination and visual acuity and (b) "higher" cognitive functions involving strategic problem solving (Tower of Hanoi) and a compensatory tracking task. On-road tests included lateral position control, assessment of traffic situations for merging and the Advanced Drivers Test.

Results were similar to the earlier study. On the one hand the brain-damaged group showed deficits on the "lower" cognitive functions tests eg. Reaction-Time, Minnesota Test, Trail Making Test, Embedded Figures Test. On the other hand, scores on tests of "higher" mental functions were the same for both the brain-damaged and non-brain-damaged group.

On-road tests however demonstrated a lower level of performance in the brain-damaged group, although only two were judged unfit to drive. In general, the group demonstrated more variability in lateral positioning and needed more time to analyse traffic in a merging situation. Despite expectations based on the hierarchical model, correlations between higher cognitive functions and driving ability were not significant. Interestingly, as noted in other studies (eg. Sivak, 1981) car positioning was related to visual-motor test performance. In addition, reaction-time measures and the cognitive planning test (Tower of Hanoi) scores related to traffic merging performance.

The most important result from this study was the authors' conclusion that "the quality of judging complex dynamic traffic situations is a cognitive factor which is not assessed by any of the tests used in our battery".

A final study to be discussed makes use of commercially produced software designed as cognitive rehabilitation programs (Schweitzer et al, 1988). The REACT (reaction-time) and SEARCH (visual search) tasks from the Computer Programs for Cognitive Rehabilitation (Gianutsos and Klitzner, 1981) were used with a tracking simulator task in one study and in addition to cognitive and in-car tests in a larger study. The tracking task simulated the in-car manoeuvres of starting and stopping, right turn from stop, left turn from stop, right turn when moving, left turn when moving, low speed serpentine tracking and high speed serpentine tracking.

Following a small pilot study with 5 disabled subjects, Schweitzer et al (1988) designed a two group study to compare the performance of 7 head-injured and 7 able-bodied drivers on the tracking and computer tasks. Correlational analysis demonstrated a significant relationship between those parts of the REACT task presented to the left side and the tracking manoeuvres involving turns to the left. The authors reported that the head-injured group performed significantly worse on these two manoeuvres and were slower responding to stimuli presented to the left. Overall the reaction-times of the head-injured group were significantly longer than the control group.

A larger three group study by the same researchers incorporated a cognitive battery of clinical measures (Table 7) and in-car tests on a closed course, together with the computer tests described above. The three groups were 10 head-injured, 7 with spinal cord damage (including one with spina bifida) and 8 able-bodied controls. The mean age of the control group at 19 years was about 10 years younger than the first two groups. In-car testing was conducted on a closed course. Eight specific manoeuvres, similar to the tracking manoeuvres, together with an emergency stop, were completed. Practice was given

TEST	SKILLS ASSESSED
WAIS:Picture Arrangement	Non-verbal reasoning
Block Design	Visual-spatial ability
Digit Symbol	Attention
Arithmetic	Immediate memory
Picure Completion	Visual discrimination
Motor Free Visual Perception Test	Visual perception
Baylor Adult Visual Perception Test	Visual perception
Trail Making Test	Visual-motor tracking
Symbol Digit Modalities Test	Attention
Driver Performance Test	Driving knowledge

TABLE 7 : Cognitive battery used by Schweitzer et al (1988).

on a small-scale vehicle before progressing to a specially adapted full-scale vehicle for testing.

There were clearcut differences in the mean driving scores of the head-injured, spinal-injured and able-bodied groups. Out of a possible score of 100, the head-injured group scored 66.4, the spinal-injured group 83.6 and the able-bodied group 94.7. In addition, all the cognitive measures except the Motor Free Test correlated significantly with driving performance. Multiple regression techniques indicated that several combinations of variables were predictive of driving performance. The authors considered that the most promising result was the prediction of driving performance by the Symbol Digit Modalities Test alone, which yielded a correlation coefficient of .69. This test is similar to the WAIS Digit Symbol subtest, requiring the substitution of numbers for randomly presented geometric designs. Schweitzer considered that this test assessed information processing speed and efficiency. Poor performance on this test might therefore be correlated with poor performance on the road.

2. SUMMARY

Studies on the cognitive abilities and driving performance of the brain-damaged driver reviewed above clearly indicate that residual cognitive deficit can be measured for a long time after the injury. However, the extent of the relationship between these cognitive deficits and driving performance is less conclusive. Table 8 presents a summary of the tests which have been found to correlate significantly with in-car performance. It should be emphasised, however, that Sivak et al (1981) were the only researchers to demonstrate a significant association between individual clinical cognitive tests and driving in normal traffic situations. As shown in Table 8, other studies were only able to demonstrate relationships between specific tests and off-road manoeuvres. Moreover, later

STUDY	TEST	TYPE OF IN-CAR TEST
Sivak et al (1981)	1.Picture Completion 2.Picture Arrangement	Road test(.72) Road test(.46)
Stokx and Gaillard (1986)	1. Choice RT	Slalom driving(.69)
Van Zomeren at al (1988)	1.Benton Visual Retention 2.Trail Making 3.Minnesota	Lateral position control(.76) " (.83) " (.96)
Van Wolffelaar et al (1988)	1.RT(movement time) 2.Minnesota 3.Trail Making A 4.Adaptive Tracking (sidewind factor)	" (.57) " (.81) " (.47) " (.74)
Korteling (1988)	1.Duration Categorisation(DCT) 2.DCT Error Rate	DCT in car(.90) DCT error(.87) Platoon following speed(.72) Platoon following brake RT(.94) As above(.54,.76, .81,.65)

TABLE 8 : Correlations between laboratory or clinical tests and in-car performance for brain-damaged groups (cond.)

STUDY	TEST	TYPE OF IN-CAR TEST
Schweitzer et al (1988)	1.Digit Symbol	Off road manoeuvres (.78)
	2.Trail Making	" " (.67)
	3.Adult VP Test	" " (.63)
	4.Symbol Digit Modalities	" " (.84)
	5.Driver Performance Test	" " (.85)

TABLE 8 : Correlations between laboratory or clinical tests and in-car performance for brain-damaged groups.

studies with head-injured drivers were unable to replicate these findings (van Wolffelaar et al, 1988). One possible explanation for this conflict might be that Sivak's group of brain-damaged individuals were of mixed aetiology and varied driving experience. The group may therefore have had brain deficits and driving performance unlike the more cohesive head-injured groups in the Dutch studies. This could be empirically determined if raw data were available, but otherwise can only be speculative.

Of interest perhaps for future development is Nouri's concept of a battery of tests weighted differently according to the contribution to driving of the specific skills measured. This battery seemed to have predictive validity for driving performance in those returning to driving after a stroke, and perhaps could be generalised to other brain-damaged groups (Nouri et al, 1987).

Also of interest in the studies shown in Table 8, are the correlations found between basic car control tasks, (primarily steering and car positioning) and laboratory or clinical tests. These correlations imply that many clinical tests assess functions at what the Dutch researchers describe as the "operational" or "lower" cognitive level. An extension of this finding is that nondrivers who perform poorly on these tests might also be those who find difficulty in developing car control during the tuition period. This is an important consideration for those with spina bifida and hydrocephalus who not only demonstrate cognitive deficit, but also steering and car positioning difficulties.

In summary, from the limited number of studies which have investigated the correlation between laboratory or clinical tests and in-car performance, the most that can be said is that certain clinical tests seem to be associated with specific car manoeuvres. The question of the contribution of clinical tests to the prediction of driving behaviour, therefore remains unresolved.

In this thesis the subject population is rather different to those in the studies discussed above. In the studies already considered, the majority of people have been experienced drivers who have suffered traumatic damage resulting in cognitive deficit. The primary concern of this thesis is the effect of congenital cognitive impairment on the acquisition of driving skills in those with spina bifida and hydrocephalus. In the next chapter we therefore turn to a description of the disabilities suffered by these young people.

CHAPTER FOUR : SPINA BIFIDA - MEDICAL, PHYSICAL AND NEUROLOGICAL ASPECTS

The primary concern of this thesis is the effect of congenital cognitive impairment on the acquisition of driving skills in those with spina bifida and hydrocephalus. Having dealt with the literature on driving in normal and brain-damaged drivers, the next three chapters will now be devoted to a description of the conditions of spina bifida and hydrocephalus and their consequences.

In order to appreciate the complexity of the nature of the cognitive deficits associated with this condition, it is necessary to be aware of two important facts. The first concerns the nature of the condition itself. As with the term "cerebral palsy", "spina bifida" is the layman's term for a conglomerate of conditions. The term encompasses, for example, those with and without hydrocephalus, varying degrees of impairment within each condition and very different patterns of motor, perceptual and cognitive deficits. As will be shown later, this means that the group is not in the least homogeneous.

The second piece of factual information that is necessary to understand the problem to be discussed, arises out of the advances in medical treatment which have taken place over the last thirty years. These have had profound effects on the composition of the SBH population. Although there are now more people surviving, many more also have a greater degree of both physical and cognitive deficit. In this chapter only the medical, physical and neurological aspects of spina bifida and hydrocephalus will be considered. Cognitive deficits are discussed in Chapters Five and Six. A glossary of the main terms used is provided in Appendix I.

1. A DEFINITION OF TERMS

1.1. SPINA BIFIDA

The condition known as "spina bifida" has been recorded in the medical literature since the sixteenth century (eg. van Foreest, 1587). Indeed one informative historical paper presents evidence that its occurrence has been noted in even earlier civilisations (van Gool and van Gool, 1986).

The term "spina bifida" literally means "split spine" and refers to a group of developmental defects in which part of the spine fails to fuse. Depending on where this occurs and the nature of the associated abnormalities, more specific terms are used to describe the underlying pathology eg. myelomeningocele, meningocele. In addition, two other related malformations of the central nervous system are frequently mentioned. These are anencephaly and encephalocele.

In anencephaly, the exterior part of the brain fails to develop, resulting in early death. Encephalocele results from a defect in the fusion of the skull and resulting herniation of the tissues. Some studies include encephaloceles among their spina bifida populations (eg. Tew and Laurence, 1975; Lonton, 1976; Tew et al, 1985), but, in general, this group presents different deficits and cannot be considered in the same context.

Despite the variety of pathological lesions subsumed under the heading "spina bifida", widespread clinical usage tends to be confined to a few main terms:- spina bifida occulta and spina bifida aperta, the latter being further subdivided into spina bifida meningocele and spina bifida myelomeningocele. The differences between these conditions are described as follows:-

SPINA BIFIDA OCCULTA : this is the least severe of the two main conditions. Although in spina bifida occulta the spine is not completely fused, there is generally no abnormality of the spinal cord or the meninges (the membranes covering the brain and spinal cord). Outward appearances are often normal or sometimes defined by a tuft of hair or mark on the skin. Function is not normally affected.

SPINA BIFIDA APERTA : this is a more serious condition in which part of the meninges herniates to form a cyst, filled with cerebrospinal fluid (CSF). When the herniation involves only the meninges the condition is termed SPINA BIFIDA MENINGOCELE (Figure 2(b)). In most cases of meningocele the nerve cells are not affected and there is little functional impairment. The most serious condition is when the spinal cord itself is abnormal and protrudes with the meninges into the cyst (Figure 2(c)). This is

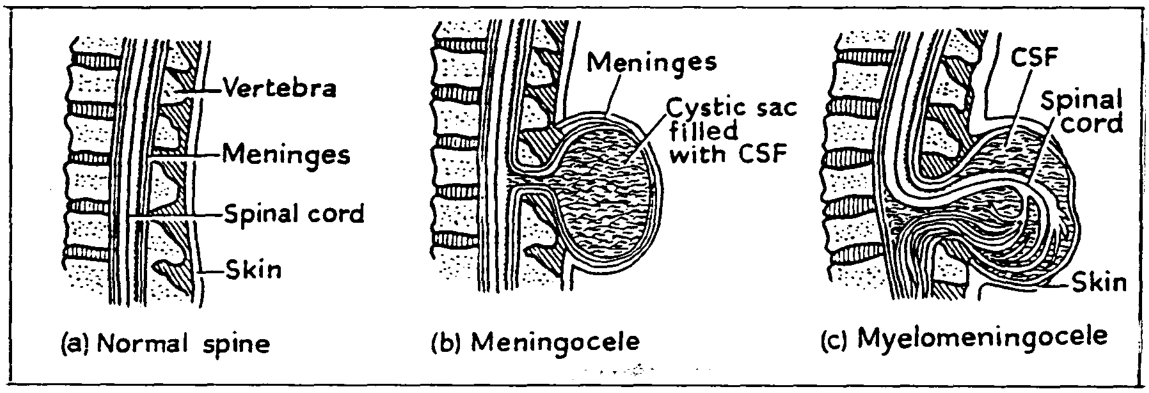


FIGURE 2 : Section through (a) normal spine, (b) meningocele, (c) myelomeningocele (Benda,1952).

termed SPINA BIFIDA MYELOMENINGOCELE and usually involves significant neurological impairment. The severity of impairment depends on the position of the defect and the number of vertebrae involved.

1.2. HYDROCEPHALUS

The additional life-threatening condition most frequently associated with spina bifida is hydrocephalus. This has been popularly, but incorrectly, labelled "water on the brain", as it develops when an abnormally large amount of cerebrospinal fluid collects in the ventricles of the brain. The occurence of hydrocephalus was noted in Greek medicine but did not begin to be understood until the eighteenth century (Morgagni, 1761; Whytt, 1768). The circulation of CSF was more fully explained by the nineteenth century, but even today is not fully understood (Magendie, 1825; Key and Retzius, 1879).

In the normal brain, CSF is formed within the ventricles, flowing from one to another through connecting channels (Figure 3). The fluid then passes into the subarachnoid space and the spinal canal. CSF is in constant circulation, absorption into the blood stream taking place in the subarachnoid space. Although hydrocephalus is sometimes caused by a production imbalance, the most common cause is an obstruction in the narrow channels between the ventricles or at the base of the brain, thereby preventing normal circulation. This blockage or imbalance can lead to a build up of CSF (termed intracranial pressure). The subsequent dilation of the ventricles can cause irreversible brain damage.

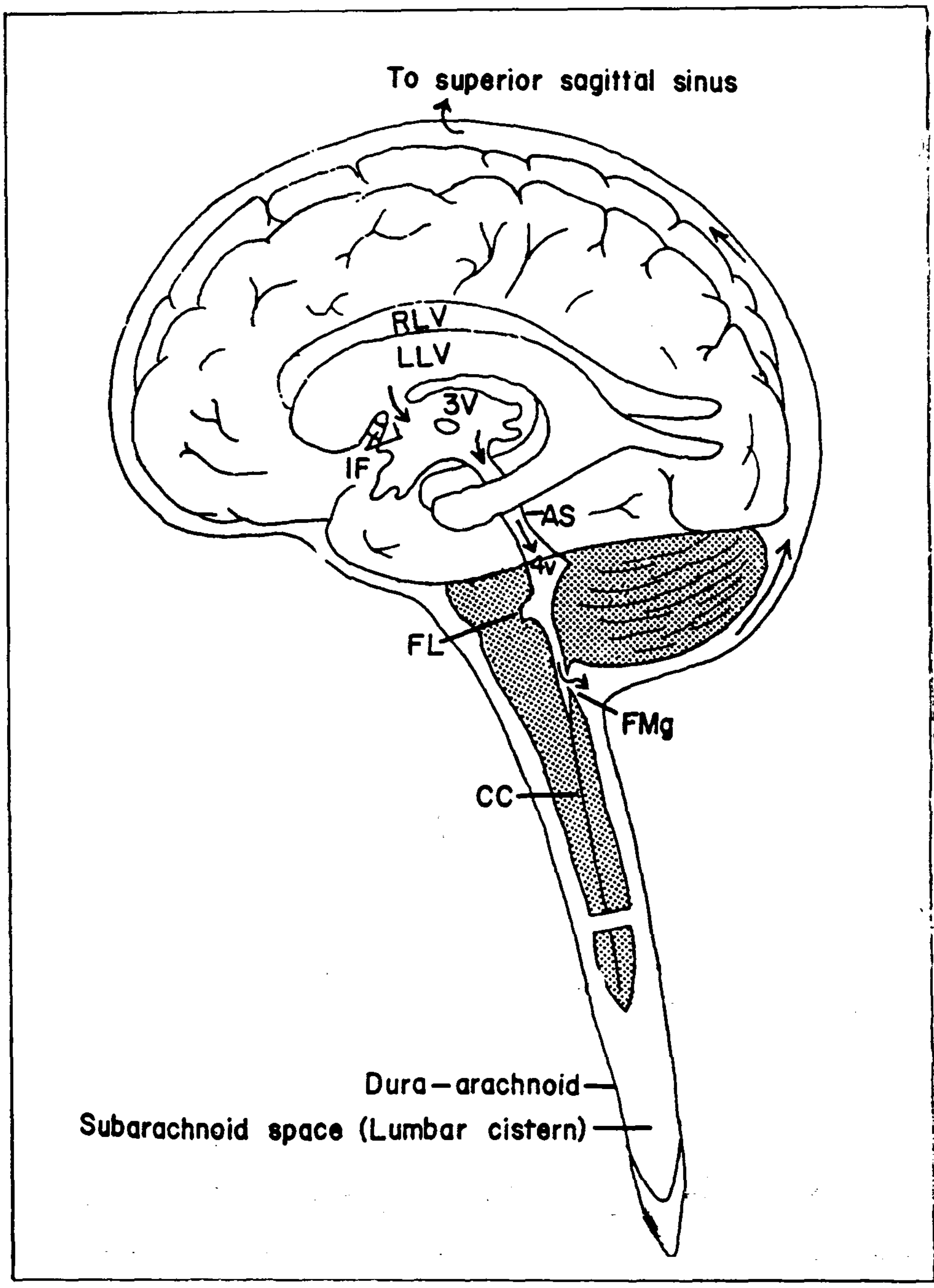


FIGURE 3 : The cerebrospinal fluid circulation. Arrow indicates direction of flow of CSF. RLV: right lateral ventricle; LLV:left lateral ventricle; 3V:third ventricle; IF:interventricular foramina; AS:aqueduct of Sylvius; 4V:fourth ventricle; FL: foramen of Luschka; FMg:foramen of Magendie; CC: central canal (reproduced from Goldberg, 1985).

1.3. ARNOLD-CHIARI MALFORMATION

Another very common concommitant of spina bifida is a defect of the lower brain stem known as the Arnold-Chiari malformation (Chiari, 1891, 1896; Schwalbe and Gredig, 1906). It is generally thought that this malformation produces obstruction of the fourth brain ventricle, thus directly contributing to the development of hydrocephalus. In this condition, part of the brain stem and cerebellum protrude downwards through the upper end of the spinal canal (foramen magnum). As the cerebellum is considered to contribute to the control and initiation of movement, it is also thought that this abnormality may be responsible for the poor hand co-ordination often noted in those with spina bifida and hydrocephalus. Brain damage attributable to hydrocephalus has also been associated with both visual and learning deficits, as described in later sections.

From this brief description of spina bifida and hydrocephalus, it may already be clear that it is the association of the two conditions that is likely to have the most serious consequences for a child's development. Not only will physical limitations due to the spina bifida restrict motor development, but other deficits resulting from hydrocephalic brain damage may also affect normal learning experiences. A further complication to be mentioned is the occurence of epilepsy in those with spina bifida and hydrocephalus (Bartoshesky et al, 1985;

Stellman et al, 1986). However, although the presence of epilepsy may well affect a child's development, for the purposes of this thesis, well controlled epilepsy in adulthood is not a bar to driving and will therefore not be further discussed (Raffle, 1985).

2. INCIDENCE

Although published figures depend to some extent on the methods used to collect data, the incidence of spina bifida at birth undoubtedly varies both within and between countries. The United Kingdom has a high prevalence rate, particularly noticeable against the very low rates of Scandinavia, Japan and Australasia (Elwood and Elwood, 1980). However, there has been a dramatic decrease in the number of babies born with spina bifida in England and Wales over the past ten years. For instance, OPCS (1990) reported a rate of 14 spina bifida births per 10,000 total births in 1978 against 2.3 in 1988. This has been largely attributed to pre-natal screening, genetic counselling and diet supplementation (eg. Laurence, 1989). However, a higher incidence of females with spina bifida, continued to be recorded, with 35% more females than males being affected in 1988.

The incidence of spina bifida births was also given a more general perspective by this recent OPCS survey. The survey reported that congenital malformation notifications for England and Wales in 1988 showed that 509 (3.9%) were for malformations of the central nervous system. Of these total births, 157 had spina bifida alone, 34 spina bifida with hydrocephalus and 137 had hydrocephalus alone. Considering the 276 live births only, the incidence rates per 10,000 were - for spina bifida only, 1.7 for males and 2.4 for females; for spina bifida with hydrocephalus, .4 for males and .4 for females; and for hydrocephalus alone, .3 for males and .5 for females.

3. MEDICAL TREATMENT FOR SPINA BIFIDA AND HYDROCEPHALUS

3.1. EARLY DEVELOPMENTS

Prior to 1960 there was little enthusiasm for performing surgery to close the back lesion of a newborn with spina bifida myelomeningocele. Complications were very likely to occur and it was generally considered that surgical intervention was of no value until there was also effective treatment for hydrocephalus. Initial attempts to treat hydrocephalus, mainly by draining the excess CSF externally had inevitably resulted in infection and a high mortality rate.

As knowledge of CSF circulation increased in the twentieth century, internal drainage systems were attempted. These systems (or shunts) allowed the excess CSF to be taken from the brain ventricle, via a tube, to another part of the body, such as the heart, where the CSF could be reabsorbed. However, the important breakthroughs did not come until the 1950s when shunts with an anti-reflux valve were developed (Nulsen and Spitz, 1952; Pudenz et al, 1957). Despite further modifications to shunts, there are undoubtedly still complications attached to the treatment of hydrocephalus. For example, shunts can become infected and blocked (eg. Bayston et al, 1983; Connolly et al, 1987). Notwithstanding, there has been a significant drop in the mortality rates over the past twenty years. Parallel with developments in the treatment of hydrocephalus in the 1960s came a renewed interest in the treatment of the spina bifida lesion itself.

In the United Kingdom, the main impetus came from a team of surgeons based in Sheffield (Sharrard et al, 1963). Initially much excitement was generated by a study which compared the lower limb function of children whose spinal lesion had been closed within forty-eight hours of birth to that of those who were operated on later. The authors of this study interpreted their results as support for a policy of early closure. They claimed that it led to a decreased mortality rate, a lower incidence of complications and improved muscle function. However, others were not able to replicate these results and the suggestion that reflex activity rather than voluntary control may have accounted for the improvement in muscle function gained credence (Brocklehurst et al, 1967; Smyth et al, 1974).

3.2. "TOTAL CARE" POLICY

Despite these setbacks, early back closure became standard practice in Sheffield and several other centres, including Liverpool and Cambridge. In order to increase the survival rate of those born with spina bifida and hydrocephalus, a policy described as "total care" was introduced. "Total care" included not only repair to the spinal lesion but insertion of a shunt if hydrocephalus developed, treatment for limb deformities and management of incontinence.

This policy clearly had an effect on the mortality rate in those areas where it was practised. In the period 1947-56, the Registrar General's figures indicated that 63% of untreated SBH babies died by one month and 89% by six months. In contrast, the policy of total care in Liverpool meant that 49% of operated babies survived three years or more (Mawdsley et al, 1967). In addition, the survival rate at two years was 62% in Sheffield (Lorber, 1971) and 65% in Cambridge (Hunt et al, 1973). However, of concern were the reports from all three centres that up to 80% of survivors were severely physically and intellectually handicapped.

3.3. SELECTION FOR TREATMENT

In the face of these facts, Lorber reviewed the Sheffield policy of "total care", concluding that routine closure should be abandoned in favour of selective treatment for only those babies with a good prognosis. His controversial paper on this topic (Lorber, 1971) outlined four adverse criteria which would determine the likely "quality of life" of a baby. These were:- the degree of paralysis, the head circumference, the presence of kyphosis (curvature of the spine) and associated gross congenital abnormalities.

A policy of early selection, therefore began in Sheffield in 1971. Adopting the four criteria, approximately 60% of babies born in Sheffield were untreated, all dying within nine months. Of those treated (12/37) only 2 died within the same period. Although these results seemed to justify the use of the four criteria for predictive purposes, there were criticisms that Lorber's predictions were self-fulfilling. The untreated babies were heavily sedated to the point that they were unaware of hunger and therefore did not "demand to be fed" - the alternative treatment for those selected out (Black, 1979).

Present day thinking is still divided on the question of selection for treatment, although most centres operate some form of selection even if not strictly based on Lorber's criteria.

Many of the young adults in this study were born from 1970 onwards. They will therefore have been treated under a "total care" policy or have been "selected in" for treatment. Treatment, in this case, does not, of course, mean cure. Many may well still demonstrate severe physical abnormalities and additional deficits associated with hydrocephalus. As far as this thesis is concerned, the two most important physical functions which might be affected are motor co-ordination and vision.

4. MOTOR FUNCTIONING

Figure 4 shows the 31 pairs of spinal nerves and the corresponding vertebrae, indicating their relationship to function. In general, the muscles which receive their nerve supply from the spinal cord at or below the level of the lesion will be affected. It can be seen from Figure 4 that three areas of functioning may be affected - the lower limbs, the upper limbs and continence (bowel and bladder control). The effects of the spina bifida lesion on lower and upper limb functioning only are discussed, as these aspects are of direct relevance for driving.

4.1. LOWER LIMB FUNCTION

The majority of those with spina bifida myelomeningocele have lesions in the lower thoracic and lumbar regions (Figure 4). They will therefore demonstrate some degree of lower limb paralysis, frequently severe enough to prevent

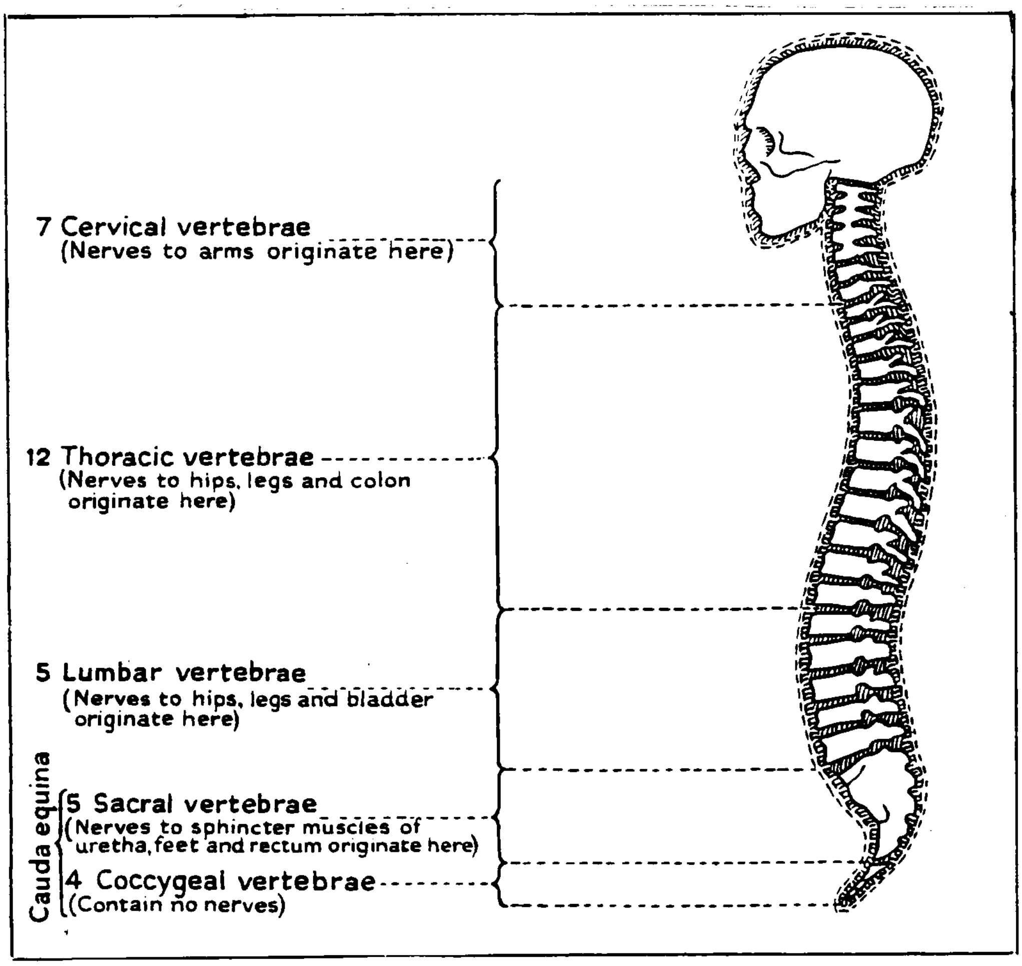


FIGURE 4 : The vertebral column, showing the relationship to function (from Anderson and Spain, 1977).

them achieving independent walking. Those with sacral lesions will be least affected, but even so, all except those with lesions below the third sacral vertebra are likely to need support for the feet when walking.

Other associated abnormalities particularly affecting mobility include curvature of the spine, dislocation of the hips and other fixed limb deformities of the legs and feet resulting from muscle imbalance.

4.2. UPPER LIMB FUNCTION

There is an increasing body of evidence indicating that functioning of the upper limbs is not always normal even when the spinal nerve damage sustained is below the cervical region. This abnormality is frequently demonstrated by poor hand-eye co-ordination. For example, Minns et al (1977), compared the results of 31 6-8 year old spina bifida children (23 with shunted hydrocephalus) and their matched controls on a series of neurological and functional tests. They found significant differences between the performance of the two groups on many of the tests. In particular, those with spina bifida with hydrocephalus demonstrated tremor, ataxia and muscle weakness on tasks such as catching a ball or using scissors. In a much larger group of 225 myelomeningocele children of "at least one year old", on the basis of a neurological examination, Wallace (1973) demonstrated abnormal upper limb function in 156 (69%) children. The predominant disorders were ataxia, mixed ataxia and pyramidal tract dysfunction. Again, hydrocephalus, whether treated or not, was significantly associated with abnormal neurological findings.

Another comprehensive study which investigated fine motor function in those with spina bifida was that of Anderson (1975). She presented a series of standardised tests of hand function to both SBH and able-bodied control groups and showed that more than half of the SBH group were slower and less accurate than the control group. In a later study with Plewis, Anderson also reported a marked difference between SBH and control groups on a dotting task (Anderson and Plewis, 1977). Those with SBH were much slower than the controls with no accompanying increase in accuracy. Both studies concluded that poor hand function was not only caused by poor hand control per se but also by an inability to plan and organise movements in space (apraxia).

The question of whether the deficits, resulting in poor motor hand control, could be described more specifically was addressed in an elegant small-scale study by Brunt (1984). In this New Zealand study, children with SBH and SB only were both included, to test the hypothesis that hydrocephalic brain damage or brain stem abnormality (Arnold-Chiari malformation) might account for deficits in motor sequencing, over and above difficulties in motor planning. Seven SBH and 7 SB children (8-16 years) were asked to complete a series of 8 simple gestures and 9 motor sequences. Examples of the items for each category were "Cross your arms and place your hands on your knees" (simple gesture) and "With both hands slap your legs and then clap your hands twice" (motor sequence). The simple actions were first performed to command and then to imitation, then the same procedure was followed for the sequences.

The results clearly demonstrated inferior performance by the SBH group. The SB only group achieved near perfect scores on all tasks and were especially competent in the command only conditions. In the "simple gestures" condition, the SBH group were significantly better when imitating, as opposed to performing to command, but the effect was only marginal for the motor sequences. Brunt put forward the view that whereas inability to map the correct movement from a verbally mediated motor plan seemed to reflect an apraxic condition, the inability to accurately imitate motor sequences was more likely to be the result of damage to those areas of the cerebral cortex responsible for movement sequencing.

The effects of hydrocephalic damage on more traditional tests of hand function were also investigated by Turner

(1986). A small group of 33 SBH and SB only children, completed tests which included throwing and catching a ball, lacing, threading beads and more formal tasks of simultaneous movements. The most important, but perhaps predictable, finding was that whereas presence and severity of hydrocephalus seemed to affect performance, no correlation was found between the level of the lesion and hand function.

These findings strongly support the view that poor upper limb function is present in many of those with spina bifida and hydrocephalus, even when the level of the lesion is not above the thoracic level. The most likely explanation, as discussed above, is that impairment of motor control is due to raised intracranial pressure and resultant hydrocephalic brain damage or to the brain stem damage inherent in the Arnold-Chiari malformation.

5. VISION

In those with spina bifida and hydrocephalus, damage to the optic nerves is generally considered to occur as a result of the stretching caused by raised intracranial pressure or occlusion of the blood supply to the nerves. The visual defects noted have included poor visual acuity, optic atrophy (one of the main causes of blindness), field loss, strabismus (squint) and eye-movement abnormalities, such as nystagmus. As there are stringent regulations governing the visual standards required by drivers, those with severe defects will be precluded from driving. This thesis will therefore only briefly mention three conditions which might affect, but not preclude driving. These are squint, nystagmus and restricted field of vision (field loss).

As might be expected, there is a difference in the incidence of visual defects in those with spina bifida alone and spina bifida with hydrocephalus. However, although a high incidence of visual defects has been consistently reported (eg. Clements and Kaushal, 1970; Tew and Laurence, 1978; Gaston, 1985) among those with SBH, more surprisingly it has been found that many of those with spina bifida only have impaired vision (Clements and Kaushal,1970). These findings are discussed in more detail in the following sections.

5.1. SQUINT

A squint is a muscle imbalance which prevents the eyes co-ordinating to produce binocular single vision. A person with a squint frequently learns to suppress the image from one eye, thus reducing the risk of double vision, but at the cost of losing depth perception. The lack of depth perception (three dimensional vision) can affect the ability to judge speed and distance.

Clements and Kaushal's detailed work indicated that the most common defect seen in those with SBH was a squint (Clements and Kaushal, 1970). They also noted some unexpected results when comparing the vision of those with SBH and those with SB alone. Not only did 82% of those with hydrocephalus squint, but also 55% of those with a diagnosis of spina bifida alone. The authors put forward the suggestion that in the latter group, mild hydrocephalus, unrecognised and spontaneously arrested (without treatment), may have been present in the first few weeks of life. The 88% incidence of squint noted in Clements and Kaushal's study was high compared to the later findings of 30% by Harcourt (1968), 40% by Tew and Laurence (1978) and 42% by Gaston (1985). However an incidence of this magnitude is quite striking when compared to the 2-3% found in the general population (Black, 1980).

5.2. NYSTAGMUS

Nystagmus is the term for involuntary eye-movements, which cause a jumping or jerky image. Sufferers may learn to stabilise the image by adopting a head posture or may suppress the movement. Nystagmus may also reduce both near and distance vision. Incidence of nystagmus in Clements and Kaushal's SBH group was 20%, whilst Gaston demonstrated a 29% incidence of "ocular motility" disorders, which included nystagmus.

5.3. VISUAL FIELD LOSS

In addition to blindness or severe field loss, optic nerve damage due to raised intracranial pressure can cause slightly restricted peripheral vision. This may have little effect on everyday activities where good peripheral vision may not be essential, but may restrict observation whilst driving. Unfortunately, although Gaston (1985) stated that the visual fields of her SBH sample were measured, she did not report on the extent of any loss.

6. SUMMARY

The medical, physical and neurological aspects of spina bifida and hydrocephalus detailed in this chapter, make it clear that those born with these disabilities may not only be disadvantaged by lower limb paralysis, but may also show impaired upper limb and visual functioning. When driving is considered, impaired lower limb function can be overcome by the use of hand controls (fitted near the steering wheel) to operate the accelerator and brake pedals. If fitted and used correctly, hand controls should not lead to other difficulties. This aspect is, therefore, not of particular focus in this thesis. Of some relevance for those with hydrocephalus, however, is the effect of poor planning and execution of motor acts. This level of difficulty could manifest itself in the more complex aspects of control such as the movements required for the operation of the accelerator and brake, together with the steering wheel. This involves not only performing different movements with each hand, but performing them simultaneously.

As far as this thesis is concerned, however, it is the cognitive deficits associated with hydrocephalic brain damage that are of primary interest. As will be shown in the following chapter on general cognitive functioning, hydrocephalus affects intellectual functioning in a variety of ways. Although those considering driving are likely to be the more able, they may still be slow learners, possibly with additional specific deficits.

CHAPTER FIVE : SPINA BIFIDA - GENERAL COGNITIVE FUNCTIONING

In the previous chapter the purely physical concomitants of spina bifida and/or hydrocephalus were discussed and those relevant to driving described in detail. It was noted that the development of surgical techniques to control hydrocephalus and to close the spinal lesion had not only had positive effects in that the mortality rate is lower than ever before, but also negative effects in that the numbers of physically and intellectually impaired survivors are greater. In this chapter we now turn to a consideration of the cognitive deficits, which are associated with this condition.

In the case of individuals who wish to learn to drive, there are two aspects of cognitive functioning which must be considered. Firstly, it seems reasonable to assume that general ability would have a bearing on a person's potential for learning to drive. Secondly, the presence of specific impairments of cognitive functioning which relate directly to the driving task, might affect the ability to drive safely. The aim of this chapter is to consider research findings relating to general cognitive functioning in children and young adults with spina bifida and/or hydrocephalus. The more specific skills to be assessed will be discussed in detail in the following chapter.

During the late 1950s and early 1960s, three comprehensive, longitudinal studies investigating spina bifida and hydrocephalus were initiated. These studies, still continuing today, are based in South Wales, Greater London and Sheffield. Each one is concerned with groups of children born during a specific period and monitored at regular intervals. (Full details are given in Appendix II.) Although similar studies have been conducted in other countries including Sweden (Hagberg, 1962) and the United States (Badell-Ribera et al, 1966; Shurtleff, 1986), this thesis will primarily refer to work in the United Kingdom.

The main objective of long term studies is to allow changes in behaviour, associated with the development of a condition, to be recorded. Naturally, such studies do not focus exclusively on cognitive functioning. The three SBH longitudinal studies considered here, also deal with questions relating to social class (Lonton and Sklayne, 1980), sex differences (Lonton, 1985) and family attitudes (Tew and Laurence, 1973; Evans et al, 1986) to name a few. However, they do include measures of IQ and much of the data to be examined comes from them.

As might be predicted from the information presented in the previous chapter, questions concerning cognitive functioning often relate to the presence or absence of hydrocephalus. Also at issue is whether the hydrocephalus has been treated (shunted) or has spontaneously arrested (stabilised without medical or surgical intervention). A further point raised in the literature is the syndrome of "normal pressure" hydrocephalus (Hammock et al, 1976). This contradictory term has been used to describe those who show behavioural symptoms of hydrocephalus in the absence of raised intracranial pressure. As shunting has been shown to reduce symptoms, a possibility put forward is that there is a greater variation of "normal" CSF pressure betwenn individuals than previously thought (Gordon, 1977). Another question is whether those with spontaneously arrested hydrocephalus demonstrate less cognitive impairment than those with shunts. As was noted in the chapter on the medical aspects of spina bifida and hydrocephalus, a clear difference exists between those who received treatment to close the spinal lesion and/or to control hydrocephalus and those who were born prior to effective treatment.

Although they are rarely dealt with consistently in the literature, within the untreated and treated groups, four subgroups can be distinguished and should be considered separately. These are:- spina bifida alone, hydrocephalus alone, spina bifida with arrested hydrocephalus and spina bifida with shunted hydrocephalus. In the sections which follow, the cognitive functioning of the two main groups - untreated and treated will be considered separately, referring to the subgroups where appropriate.

Before turning to the data, it should be noted that the measures used to assess cognitive functioning vary from study to study. For example, one study used the Griffiths Mental Development Scale (Laurence and Coates, 1967), whilst another retrospectively reported IQ scores from the Stanford-Binet Intelligence Scale (Tew et al, 1985). By far the most common, however, are the various forms of the Wechsler Scales (Wechsler, 1939, 1949, 1955, 1967, 1974, 1981). Although all versions of these tests were designed to make separate assessments of verbal and non-verbal skills, they are not of course perfectly correlated, which makes it difficult sometimes to compare results. However, to clarify the meaning of the IQ scores quoted in the research findings to be discussed, Wechsler's classifications of intellectual ability, ranging from mentally deficient to very superior, are given in Table 9.

IQ RANGE	CLASSIFICATION
130 and above	Very superior
120 - 129	Superior
110 - 119	High average
90 - 109	Average
80 - 89	Low average
70 - 79	Borderline
69 and below	Mentally deficient

TABLE 9 : IQ ranges and classifications from the Wechsler Scales.

1. UNTREATED GROUPS

Prior to the setting up of the Greater London longitudinal study in 1967, an early series of studies, examined general cognitive ability in an untreated London population. In the first of these studies, Laurence and Coates (1962) considered the 81 survivors of 182 cases of arrested hydrocephalus, seen at Great Ormond Street Hospital during the period 1938-57. Only 12 of this group had hydrocephalus associated with spina bifida. All children were under 13 years of age at the time of the first study. The average IQ of the whole sample was reported as 69, although no details of the tests used were given. Seventy-three percent were reported as having IQs greater than 50 and 38% greater than 85.

On reassessment five years later, 76 of the original group were still alive (11 of the 12 with spina bifida) and an additional 6 cases of arrested hydrocephalus (1 associated with spina bifida) were added to the group, bringing the total to 82 (Laurence and Coates, 1967). Using mainly the Griffiths Mental Development Test, the Stanford-Binet Test or the Wechsler Adult Intelligence Scale (WAIS), the average IQ for all cases of arrested hydrocephalus had increased slightly to 70. The percentage of children with IQs greater than 85 had increased from 38 to 45, and the percentage of those with IQs over 50 had increased from 73 to 75. Another important finding, not clearly reflected in these percentages, however, was the change in distribution of test scores. Twenty children showed a significant improvement in IQ (more than 10 points) and 10 gross deterioration. The authors did not provide an adequate explanation of the increased IQs, but considered the change at the lowest IQ levels, to be a function of the poor prognosis for those with severe hydrocephalus.

In both these studies, the children were graded on 4 levels according to severity of physical handicap (Laurence and Coates, 1962, 1967). Seven of the 12 with hydrocephalus plus spina bifida were in the most severely impaired groups. The authors reported a marked negative correlation between physical handicap and IQ in both studies, but more marked on reassessment, due to the change in IQ distribution. When those with hydrocephalus plus spina bifida were excluded from the analysis, however, a slightly different picture emerged (Laurence, 1969). There was a decrease from 45 to 41 in the percentage of those with IQs over 85 and a decrease from 75 to 71 in the percentage of those with IQs over 50. As seven of the twelve with SBH had been reported as being severely physically impaired, and in addition of low IQ, the overall decrease in the percentage of those with IQs over 50 in the hydrocephalus only group demonstrated that the remaining 5 SBH children probably had IQs in at least the average range.

Two further studies of untreated children are of particular interest. Firstly, Stephen (1963) considered two groups of SB children with and without hydrocephalus. She found that significantly more children with associated hydrocephalus had IQs below 80 than those with SB alone. However, a wide variation of IQ scores was reported both in this and in the second study, reported from the New York University Medical Centre (Badell-Ribera et al, 1966).

In this American study, a group of 75 SB patients (5-21 years), 47 with hydrocephalus and 28 without hydrocephalus, were found to have IQs ranging from 45 to 146, assessed on the WAIS or the WISC. The mean IQ of the SB only group was 109, compared to 87 for the SB group with hydrocephalus. As in the Great Ormond Street studies discussed above (Laurence and Coates, 1962, 1967), the 75 cases were also divided according to severity of physical disability. Similar findings emerged, the authors reporting that the mean IQ decreased as physical disability increased. It was also demonstrated that those with the greatest degree of physical disability and the lowest IQs were also more likely to have hydrocephalus.

On the basis of this selective review of the early studies, the following tentative conclusions can be drawn concerning the natural history of those born with spina bifida and/ hydrocephalus. Firstly, the majority of those with "spina bifida only" are likely to be within the "normal" range of intelligence ie. IQ 80-85 or above. Secondly, when spina bifida is associated with hydrocephalus, cognitive functioning, is likely to be impaired.

It should be remembered, of course, that before effective treatment, only the less physically and intellectually impaired survived childhood. What we are primarily concerned with now, is the effect of shunting on general cognitive functioning.

2. TREATED GROUPS

Widespread treatment began in the 1960s. As the earlier group of untreated survivors had tended to be those who were less impaired, perhaps it was inevitable that there was so little anticipation of the additional difficulties that treated children might experience. These difficulties were to include the effects of hydrocephalus on learning as well as those related to physical handicaps.

The lack of knowledge concerning the learning difficulties associated with hydrocephalus came from two sources. Firstly, there was limited factual information available; and secondly, the children themselves frequently presented as bright, talkative and friendly. Although this apparent verbal facility is now known to be a manifestation of hydrocephalus, in the 1960s it helped confirm popular belief that most SBH children were not intellectually impaired. Since that time information has been accumulated which has tempered these earlier views.

As was also mentioned in Chapter Four, the introduction of a total care policy in Sheffield, meant that all children were treated at birth. In the third longitudinal study mentioned earlier, in order to evaluate the long-term prospects of treatment on survival and quality of life, Lorber (1971) considered in detail the outcome of two series of treated children born in the periods 1959-63 (323 children) and 1967-68 (201 children).

The results of this comparison were surprising. Lorber reported that although the two year survival rate rose from 50% in the first group to 64% in the second group, this increase "was not paralleled by an improvement in the quality of the survivors". Moreover, intellectually there seemed to be little difference between the groups. Only 65% of each group had IQs above 80, 20% IQs 61-80 and the remainder was severely retarded. Although all children were unselected and therefore treated surgically when necessary, the second series may have received "better" care due to the advances in medical knowledge over the period. As a result, one might have expected there to be differences in the IQs of the 134 survivors in the first series and the 125 survivors in the second series.

One of the most important studies to investigate differences in intellectual functioning between SB children with and without shunted hydrocephalus was that of Tew and Laurence (1975) in Wales. The group comprised 59 children, 20 without hydrocephalus, 8 with arrested hydrocephalus (ie. untreated) and 31 with shunts. These children and 56 matched able-bodied children completed the Wechsler Pre-School and Primary Scale of Intelligence (WPPSI) at 5 years of age. As shown in Table 10, the mean IQs for the four groups - SB with shunted hydrocephalus (SBSH), SB with arrested hydrocephalus (SBAH), SB only (SB) and controls - illustrated the fairly consistent finding that mean intellectual ability is adversely affected by the presence of hydrocephalus.

Moreover, Tew and Laurence believed that this study also showed that even those with SB and no hydrocephalus were of below average intelligence, their mean IQ of 89.9 being more than one standard deviation below the British mean score of 105 (Brittain, 1969; Yule et al, 1969). From their findings the authors drew the general conclusion that spina bifida, whether or not with associated hydrocephalus, is generally accompanied by intellectual deficits. However even this conclusion needs to be tempered

GROUP	SBSH	SBAH	SB	CONTROLS
	n=31	n=8	n=20	n=56
Mean IQ	70.03	83.87	89.90	105.99
SD	21.82	21.67	25.05	14.98
Range*	35-125	50-115	35-125	75-130

TABLE 10 : WPPSI IQs for 59 SB children with shunted hydrocephalus (SBSH), arrested hydrocephalus (SBAH), no hydrocephalus (SB) and 56 controls. * approximate figures taken Tew and Laurence, 1975.

by consideration of the wide range of ability (IQ 35-125) found within the three SB groups in this study. Overall nearly 50% of the impaired children had IQs above 80. It was only the shunt-treated SBH group that could be considered to show a general intellectual deficit, three quarters being below IQ 80.

The adverse effects of shunting on intelligence were also strikingly shown by Carr and her colleagues in the Greater London Study (Carr et al, 1983). They noted that as the number of shunt revisions increased from 1 to 5, measured intelligence decreased from 85 to 72. Moreover, the children who had had more than 5 shunt revisions had an even lower mean IQ of 65. However, these results need to be carefully considered in relation to the earlier findings of

Puri et al (1977). These authors demonstrated that not only did the number of revisions affect later intelligence, but also the timing of the first shunt and the reason for the shunt revisions.

Puri et al (1977) made an intellectual assessment of 41 subjects (4-18 yrs) with hydrocephalus alone, using the WISC for all but 8 young children tested on the Stanford Binet or Cattell Intelligence Scales. Although the resulting scores showed a wide range of intelligence (IQ:46-126), the 31 whose first shunt insertion was before 6 months of age had a mean IQ of 90, compared to 68 for those whose shunt was inserted from 6 months to two and a half years. In addition, those who required revisions within the first year had a mean IQ of 65, compared to IQ 87 for those not needing revision until at least 15 months after insertion of the first shunt. More importantly, the nature of the revision affected later intelligence. Those requiring revision for prophylactic lengthening achieved a mean IQ of 92 compared to IQ 69 for those who had had a shunt blockage or infection.

Several studies have considered the more general effects of treatment on intelligence, with interesting results. Lonton (1981) in Sheffield, Sklayne (1981) in Manchester and Tew et al (1985) in South Wales, comparing groups pre- and post-selection, demonstrated an overall improved level of intellectual functioning in those "selected in" for treatment. This is of course understandable, as prior to selection all babies were treated regardless of severity of handicap, whereas the "selected in" group only comprised those who fulfilled the selection criteria. Those "selected out" would not be expected to survive.

It is therefore of interest to compare the data provided by Tew et al (1985) on three SB groups, described as "unselected" (born 1964-1966), "selected in" and "selected out" (born 1973-1978). In the latter group were 16 children, initially untreated, as they showed adverse physical criteria at birth. Treatment was given when it was evident that they would survive. All children had completed the WPPSI or the Stanford-Binet Test at five years.

The results showed the expected significant differences between the "selected in" and the other two groups. The "selected in" group achieved an average IQ of 89.8, 10 points higher than the "unselected" group, whereas the mean IQ for the "selected out" group was lowest at 73.3. However it is important to note that both the "selected in" and "unselected" groups each included nearly 50% of children without hydrocephalus or with spontaneously arrested hydrocephalus. In view of this the "selected out" group, all but two having shunt-treated hydrocephalus could be considered to have scored relatively well.

So far, from the studies reviewed, the tentative conclusions to be drawn on the treated groups are as follows. As before, the majority of those with "spina bifida only" are likely to be within the low average range of intelligence ie. IQ 80-90. Overall the figures are slightly lower than for untreated groups. In addition, as expected, when spina bifida is associated with hydrocephalus, those with arrested hydrocephalus demonstrate higher cognitive functioning than those with shunts. However, cognitive functioning is still likely to be impaired in both groups.

3. SUMMARY

This selective review of studies investigating the cognitive functioning of those with spina bifida and/ hydrocephalus, both before and after the introduction of effective treatment, has confirmed the adverse affects of hydrocephalus on general level of intelligence. It is now also apparent that those with spina bifida and shunted hydrocephalus are likely to be more impaired than those with arrested hydrocephalus.

CHAPTER SIX : SPECIFIC COGNITIVE DEFICIT

As noted in Chapter Two, the specific aspects of cognitive functioning considered likely to be important for driving include visual-perceptual skills, such as figure-ground discrimination and visual scanning. The ability to make quick, accurate judgements in complex situations would also seem essential for dealing effectively with traffic situations. Also to be considered for learning to drive are memory and attentional skills.

The studies to be reviewed in this chapter fall into two broad categories. The first category largely reviews studies which have examined group profiles on tests such as the Wechsler Scales (eg. Lonton, 1976; Tew and Laurence, 1978). These studies represent the move away from the overall scores produced by IQ tests to a consideration of subtest profiles. This move, which began in the 1970s, eventually led to the use, and often the design, of specific tests to assess particular aspects of cognitive functioning. For example, the Frostig Developmental Test of Visual Perception (Frostig, 1966) was used to consider aspects of visual-perceptual functioning by Sand et al (1973) and Tew and Laurence (1975); the Bender-Gestalt Test (Bender, 1946) was used to measure children's visual-motor development in the studies of Miller and

Sethie (1971), Tew and Laurence (1978) and Sklayne (1981). Studies using these, and other tests, form the second category for consideration in this chapter.

1. WECHSLER SCALES PROFILE ANALYSIS

As briefly mentioned in the previous chapter, over the years, Wechsler has developed several different forms of his original scale, but all constructed in the same way ie. with groups of tests designed to assess verbal and non-verbal (performance) skills. Although the Wechsler Scales were not originally designed as neuropsychological tests, their use as diagnostic instruments in clinical practice has developed over the years. The most frequently used measure has been the discrepancy between Verbal and Performance Scale IQs. The selective review which follows reports the findings of the main studies which evaluate the relative performance of spina bifida groups on the Wechsler Verbal and Performance Scales.

Frequent use of the Wechsler Scales with spina bifida children has revealed some interesting trends. Although the topics of the studies using these Scales are wide-ranging eg. laterality (Lonton, 1976); level of lesion (Lonton, 1977); ocular defects (Tew and Laurence, 1978), the clearest findings are from studies which have considered the relative performance of spina bifida groups with and without hydrocephalus. Two studies, already mentioned in the previous chapter, are of particular interest here, as they very clearly demonstrate differences in verbal and performance functioning on the Wechsler Scales. The first paper to be considered, reported the work of Tew and Laurence (1975) in South Wales. In the second paper, Halliwell et al (1980) presented preliminary findings from the Greater London longitudinal study, later to be fully reported by Carr et al (1983).

In the first study, Tew and Laurence (1975) considered the intellectual ability of 3 SB groups (no hydrocephalus, arrested hydrocephalus and shunted hydrocephalus) and a matched control group, at 5 years of age. As shown in Table 11, not unexpectedly, the control group demonstrated overall intellectual ability within the average range (mean Full Scale WPPSI IQ: 106). In the group with spina bifida only, most scored in the low average range on all three indices (Full Scale IQ: 90, Verbal IQ: 89, Performance IQ: 92). However, as can be seen from Table 11, there is a decrease in IQ scores for all Scales, depending on presence and degree of hydrocephalus. In contrast, those with arrested hydrocephalus were only borderline to low average IQ according to Wechsler's classifications (Full Scale IQ: 84, Verbal IQ: 88, Performance IQ: 82). Moreover, the group with shunted hydrocephalus were markedly lower with

STUDY	FINDINGS		
TEW and LAURENCE (1975) WPPSI	VIQ	PIQ	FSIQ
59 Controls	106	106	106
20 SB only	89	92	90
8 SBH no shunt	88	82	84
31 SBH shunted	78	67	70
HALLIWELL et al (1980) WISC	VIQ	PIQ	FSIQ
45 Controls	110	111	112
22 SB only	104	104	104
8 SBH no shunt	89	92	90
67 SBH shunted	84	77	80

TABLE 11 : Two studies reporting Verbal (VIQ), Performance (PIQ) and Full Scale (FSIQ) IQs from the Wechsler Scales.

all scores below average (Full Scale IQ: 70, Verbal IQ: 78, Performance IQ: 67). Most importantly, it was noted that the only significant discrepancy between Verbal and Performance IQs was in the SB group with shunted hydrocephalus, scores being poorer on performance tests.

A similar picture was seen in the second study under consideration, a report on the Greater London cohort at 11 years (Halliwell et al, 1980). As shown in Table 11, the overall scores for the three groups (SB only, with arrested hydrocephalus and shunted hydrocephalus) were higher than those found in the South Wales study. This may well reflect the tests used (WPPSI versus the WISC) and the age groups, as well as the different geographical areas. For example, at 5 years, the Full Scale IQ of the South Wales group with SB only was 90, whilst at 11 years in Greater London, it was reported as 104. However, when IQ profiles were considered for the London group, a similar pattern was seen. Whereas those with SB and arrested hydrocephalus scored within the low average range, overall a marked Verbal-Performance Scale discrepancy was noted in the SB group with shunted hydrocephalus. Again, scores were lower on the Performance Scale.

As mentioned in the previous chapter, the effect of shunt revision on intelligence was also analysed in both these studies, with differing results. On the one hand, Tew and Laurence (1975) found that the mean Full Scale IQ of 74 of those without shunt revisions was not statistically different to the 69 of those with one or more revisions. In contrast, Halliwell et al (1980), in a more detailed analysis, found that as the number of revisions increased, measured intelligence significantly decreased from Full Scale IQ 89 for those with no revisions to IQ 65 for those with five or more revisions. Moreover, discrepancies of up to 12 points between Verbal and Performance Scale IQs were noted in those with up to four shunt revisions. For example, the group of 15 SBH children with 2 revisions demonstrated a Verbal-Performance discrepancy of 11 points

(Verbal IQ: 84, Performance IQ: 73). Of particular interest was the additional finding that the group of 9 children with more than 5 revisions demonstrated an overall low IQ of 65, but with no discrepancy between Verbal and Performance Scales (Verbal IQ: 68, Performance IQ: 68).

The reasons for, and the timing of, shunt revisions were not considered by the authors of this Greater London study, but it seems likely that continual shunt revisions may lead to greater intellectual impairment. A further point might also be considered. As the majority of shunts are inserted in the right hemisphere, brain damage caused by surgical procedures cannot be excluded from contributing to poor performance skills (Grant et al, 1986).

One further point should be taken into consideration when examining the Verbal and Performance Scale IQs of those with spina bifida and shunted hydrocephalus. Rutter et al (1970) emphasised that due to the error of measurement inherent in test results, a difference of 25 points between Verbal and Performance IQs would be required before the discrepancy could be considered abnormal. They also stated that 6% of the general population were likely to demonstrate such a marked discrepancy. Furthermore, Kaufman later pointed out that a quarter of the WISC-R standardisation sample demonstrated a Verbal-Performance Scale discrepancy of 15 points or more (Kaufman, 1980). In neither of the studies reviewed above were discrepancies of this magnitude seen. Results therefore need to be interpreted cautiously, even in groups with known brain damage, such as those with hydrocephalus.

Bearing these points in mind, the following tentative conclusions can be drawn from the two studies reviewed above. Firstly, in SB groups with no hydrocephalus or spontaneously arrested hydrocephalus, IQ scores are in the low average range with no marked discrepancy between verbal and performance functioning. In contrast, in SB groups with shunted hydrocephalus, IQ scores tend to be below average, with a marked Verbal-Performance Scale discrepancy in favour of verbal skills.

2. TESTS FOR SPECIFIC COGNITIVE DEFICIT

The Wechsler Scales have provided a valuable insight into the cognitive functioning of those with spina bifida with and without hydrocephalus. The section which now follows considers research results on cognitive functioning which are close to the abilities tested on the Performance Scales, but using specific tests. This first part reviews studies relating to visual-perceptual motor deficits. A second important section considers the possible contribution of memory impairment to learning difficulties.

2.1. VISUAL-PERCEPTUAL MOTOR DEFICIT

A literature search revealed 11 main studies which have used a combination of clinical and/or experimental measures to investigate visual-perceptual motor deficit in those with spina bifida and hydrocephalus (Table 12). These include results from the three major longitudinal studies in South Wales, Greater London and Sheffield and two studies from outside the UK (Sand et al, 1973; Gluckman and Barling, 1980).

As can be seen in Table 12, some investigators have used standardised tests to study visual-perceptual motor difficulties. For example, the Performance Scale from the Griffiths Mental Development Test (Griffiths,1954) was used by Spain (1970,1974); the Bender Visual-Motor Gestalt Test (Bender, 1946) by Miller and Sethi (1971), Tew and Laurence (1978) and Sklayne (1981); and the Frostig Developmental Test of Visual Perception by Miller and Sethi (1971), Sand et al (1973) and Tew et al (1985). Others have designed special tests to assess aspects of functioning such as lateralisation (Grant et al, 1986) and "body image" (Robinson et al, 1986).

In line with the findings, summarised so far, one important study using standardised tests, considered the difference between very young SBH groups with and without shunted hydrocephalus (Spain, 1970, 1974). This Greater London

STUDY	SUBJECTS	TEST USED
UK STUDIES		
South Wales Study		
Tew and Laurence (1975)	29 SBH (shunt) 8 SBH (no shunt) 18 SB 56 Controls Age:5 yrs.	Frostig
Tew and Laurence (1978)	55 SB/SBH 55 Controls Age:10 yrs.	Bender-Gestalt Stott
Tew et al (1985)	59 SBH (shunt) 10 SBH (no shunt) 29 SB 56 Controls Age:5-16 yrs.	Frostig Stott
Greater London Study		
Spain (1970,1974) (Greater London)	86 SBH (shunt) 40 SBH (no shunt) Age:1/3 yrs.	Griffiths Scale

TABLE 12 : Main studies investigating visual-perceptual motor functioning in spina bifida/hydrocephalic groups (cond).

STUDY	SUBJECTS	TEST USED
Sheffield Study		
Parsons (1972)	13 SBH (shunt)	Minnesota Form Bd
	23 SBH (no shunt)	Mech. Comprehension
	20 SB	Purdue Pegboard
	Age:14-15 yrs.	
Sklayne (1983)	88 SB/SBH	Bender-Gestalt
	Age:3-17 yrs.	
Other Studies		
Miller and Sethi	14 H/SBH	Bender-Gestalt
(1971) (Hull)	14 Controls	Frostig
	Age:5-15 yrs.	Card Sorting
Grant et al	98 SBH (shunt)	British Ability Sc.
(1986) (London)	Age:10-12 yrs.	Lateralisation Tasks
		Visual Neglect Task
Robinson et al	12 SBH (shunt)	Body Size Estimation
(1986) (London)	12 Controls	
	Age:12-16 yrs.	

TABLE 12 : Main studies investigating visual-perceptual motor functioning in spina bifida/hydrocephalic groups (cond).

sample comprised 40 children without shunts and 86 with shunts. As this study involved young children, Scales from the Griffiths Mental Development Test were administered at one and three years. It was noted that the shunted group

STUDY	SUBJECTS	TEST USED
STUDIES OUTSIDE THE UK		
Sand et al (1973) (USA)	26 SBH 11 SB Age:4-7 yrs.	Frostig
Gluckman and Barling (1980) (South Africa)	14 SBH (shunt) 11 SBH (no shunt) Age:7 yrs.	Frostig

TABLE 12 : Main studies investigating visual-perceptual motor functioning in spina bifida/hydrocephalic groups.

was particularly poor on tasks involving manipulative ability and the appreciation of spatial relationships. This deficit became more marked between one and three years, when 80% of unshunted children were seen to be developing normally compared to only 33% of shunted children.

Many studies with older children have used either the Bender-Gestalt Test or the Frostig Test to assess visual-perceptual motor relationships. Whereas the Bender-Gestalt Test involves copying geometric shapes of varying complexity, the Frostig Test consists of five pencil and paper subtests considered to assess eye-hand co-ordination, figure-ground discrimination, constancy of shape, position in space and spatial relationships.

One of the earliest published studies using both the Frostig and the Bender-Gestalt Test was that of Miller and Sethi (1971). Fourteen hydrocephalic children, some with spina bifida (unfortunately exact diagnoses are not given) aged 5-15 years, with reported IQs in the 70-105 range, completed both tests. According to tests norms, there was a significant 18 month "lag" between chronological age and "perceptual" age on both tests. According to the authors, the two primary areas of difficulty were the inability to perceive a shape as a whole (a gestalt) and the inability to ignore irrelevant aspects of a display (figure-ground discrimination).

Considering the known motor difficulties of those with hydrocephalus, the authors considered that tests requiring drawing ability might put hydrocephalic children at a disadvantage. To further isolate the visual-spatial component of the task, Miller and Sethi, in a second experiment, reported in the same paper, attempted to minimise verbal encoding of shapes and motor co-ordination by using unusual stimuli in the form of Hindi letters.

Sixteen hydrocephalic children and their matched neurologically normal controls (aged 7-15 years) were tachistoscopically presented with a series of 20 Hindi letters. After each presentation they were asked to choose which of 5 letters on a card was identical to the one presented. The hydrocephalic group achieved a mean of 12.3 (range: 4-20) responses correct, compared to a mean of 19.1 (range 17-20) for the control group. The authors reported very little overlap between the groups, differences being significant at the .001 level.

A further task in this interesting study attempted to assess the contribution of stimulus complexity to figure-ground discrimination. The question to consider was whether a conflicting background increased total stimulus complexity in addition to figure-ground discrimination per se. Miller and Sethi devised an elegant task in which three decks of cards each contained either 5x5, 4x4 or 3x3 matrices with crosses distributed at random in the squares. The design of the stimuli was based on information theory (Fitts, 1954). The information value of the three packs was 51.15, 28.95 and 11.56 bits respectively. The cards in each pack had to be sorted into two piles according to whether the stimulus matrix at the top of the card was identical to the left or right of the two below it on the card. A fourth critical condition used a 3x3 matrix embedded in a 5x5 array so that the outer border contained redundant information ie. the same fixed pattern for all stimuli.

The time taken to sort the 20 cards in each pack was measured for 10 children with hydrocephalus (mean age: 10.3 years, range: 8-13 years) and 10 matched controls. The relationship between speed of sorting and task complexity, demonstrated the greater difficulty of the hydrocephalic group in responding to key stimulus (Table 13). The performance of the groups on Condition 4, the stimuli with redundant information, was particularly interesting. The control group was slightly faster on Condition 4 than Condition 3 (5x5) but did not reject the irrelevant information at the expected level (ie. sorting times were expected to be the same as for the 3x3 matrix). The control group sorted under Condition 4 as though the stimuli had an information level of 36.8 bits rather than 11.56, whereas for the hydrocephalic group the corresponding value was 81.7 bits.

The conclusion drawn by the authors was that the hydrocephalic children not only had difficulties in figure-ground discrimination, but in addition had a severe deficit in the perception of visual-spatial relationships not associated with motor impairment or verbal mediation.

Other findings from studies using the Frostig Test, although less clear, in general provide evidence that those with spina bifida with hydrocephalus have greater visual-perceptual motor difficulties than those with

CONDITION		3x3	4x4	5x5	3x3 in
GROUP					5x5
HYDROCEPHALICS	Mean	168.3	185.5	211.0	247.5
	SD	72.1	83.3	87.9	90.4
CONTROLS	Mean	72.0	117.5	160.9	153.5
	SD	20.7	38.2	53.5	64.5

TABLE 13 : Sorting times for hydrocephalic and control groups according to stimulus compexity (Miller and Sethi, 1971).

spina bifida alone (Sand et al, 1973; Tew and Lawrence, 1975). In addition, from their data, Tew and Laurence suggested that visual-perceptual functioning might be associated with low intelligence as the distribution of scores on the Frostig Test was similar to IQ distribution, measured by the WPPSI.

Adopting a different strategy, a clearly presented study by Gluckman and Barling in South Africa, investigated the beneficial effects of the Frostig Remedial Program (Frostig and Horne, 1964) on visual-perceptual functioning. Thirty-six seven year old children with spina bifida and hydrocephalus (14 with shunts) were randomly allocated to three groups - treatment, attention placebo and control.

The mean IQ of the whole group was 86, but neither the test used nor group data was given. Pre-test perceptual quotients on the Frostig Test for the three groups were 85, 83, 78 (norm=100).

The results seemed impressive. After a six month period, the treatment group, which had received weekly training using the Remedial Program, achieved a perceptual quotient of 94 (within the normal range), whilst the other two groups scored at their pre-test levels. Eight weeks later at maintenance testing, significant improvement was still in evidence in the treatment group, although scores were slightly lower. Gluckman and Barling (1980) were firmly convinced that this study clearly demonstrated the value of the Frostig Program in reducing visual-perceptual motor dysfunction. However, no evidence was given that suggested a generalisation to everyday activities such as dressing, reading and writing, tasks frequently affected by visual-motor deficit.

Whereas most studies so far have focussed on children, an early study by Parsons (1972) specifically considered the visual-perceptual skills of the spina bifida adolescent - in this instance with a view to work potential. Tests included were the Minnesota Form Board (Likert and Quasha, 1948), Mechanical Comprehension (Bennett, 1949) and the Purdue Pegboard (Tiffin, 1968). Results indicated that those with hydrocephalus, whether shunted or not, performed poorly on tests compared to those with SB alone. The performance of those with spina bifida and hydrocephalus was particularly poor on tasks involving spatial skills and manual dexterity.

Although conclusions must be tentative, the weight of data from this selective review of the visual-perceptual motor functioning of those with spina bifida and/or hydrocephalus seems to point to two consistent findings. Firstly, many of those with SBH demonstrate visual-perceptual motor deficits in both standardised and specific tests. Secondly, in particular, the visual-perceptual motor skills most markedly affected are those involving figure-ground discrimination (eg. Miller and Sethi, 1971) and visual-spatial ability (eg. Parsons, 1972; Spain, 1974).

2.2. MEMORY AND ATTENTION

In contrast to the number of studies investigating the visual-perceptual motor functioning of those with spina bifida and / hydrocephalus, relatively little research has considered memory and attentional skills. Early work on the memory skills of those with hydrocephalic brain damage took place before the more dynamic concept of working memory came to the forefront (Baddeley, 1986). Discussion at that time, therefore, tended to centre on the relative deficits of immediate memory span and long term memory (eg.

Richardson, 1978; Tromp and van den Burg, 1982).

The excessive verbosity found among some hydrocephalic children has often been thought to indicate a good memory for verbal information. In contrast, more detailed observations by teachers has indicated that SBH children find learning new information difficult unless it is presented in a simple, structured and meaningful way. Descriptions of children's classroom functioning has often demonstrated adequate memory for short, isolated pieces of information compared to poor delayed recall or recall of information exceeding attention span. Whether this is truly a memory impairment however is open to question. Inattention, poor reasoning ability or the failure to use appropriate strategies for retention of information will undoubtedly affect quality and quantity of retention.

The section which follows reviews selected studies which have revealed interesting findings in the learning ability of children with hydrocephalic brain damage. The first of these studies considered the effects of irrelevant information on the performance of SBH children (Horn et al, 1985). The second study more directly evaluated the verbal learning ability of hydrocephalic children (Tromp and van den Burg, 1982).

The adverse effect of increasing stimulus complexity on the ability to make perceptual discriminations has already been mentioned in the previous section on visual-perceptual motor deficit (Miller and Sethi, 1971). The possibility that the inability to ignore redundant information could also contribute to the hydrocephalic child's learning difficulties is therefore an interesting one.

In the American study, mentioned above, Horn et al (1985) considered the ability of SBH children to ignore distracting visual stimuli when completing both verbal and non-verbal tasks. In this study, pairs of SBH and control children, matched on mental age (mean: 81 mths), first completed a simple card sorting task to establish a baseline sorting time. This was followed by the sorting of card decks containing additional figures or coloured backgrounds as the irrelevant information.

Surprisingly, Horn and her colleagues reported that accuracy of sorting was high for both SBH and control groups. Less unexpected was the finding that the SBH group was slower than the control group on all sorting tasks. The most important finding, however, was that the interference effects due to the irrelevant visual information on the later decks, were greater and lasted longer for the SBH group. The control group quickly learnt to ignore the irrelevant information, sorting times becoming almost as fast as on the baseline trial.

On a second task, the groups were tested for comprehension of relational words, adapted from the Boehm Test of Basic Concepts (Boehm, 1971). The child was asked to point to a drawing which illustrated the word to be tested. For the baseline items simple line drawings were used. For the condition with distracting visual stimuli, the line drawings were redesigned to include additional background items. The results confirmed the findings from the non-verbal test, that those with spina bifida and hydrocephalus performed more poorly when irrelevant information was present than when it was not.

In the classroom situation, the background noise of other children's activities might be considered a source of distraction and therefore "information to be ignored". The ability of SBH children to focus attention on the task in hand in the face of competing or distracting stimuli was specifically considered by Tew et al (1980). This study was initiated by earlier findings on the South Wales cohort, in which teachers rated their SBH pupils as more "inattentive" than an able-bodied control group (Tew and Laurence, 1975).

Tew et al (1980) measured the visual scanning performance of spina bifida groups, with and without hydrocephalus, and a control group, matched on age (11 yrs) and IQ (84), under quiet versus "classroom-like" conditions. Visual scanning was measured by a letter cancellation task. In the "classroom-like" condition, classroom noise was presented via headphones.

The results were interesting. In common with the findings of Horn et al (1985), described earlier, under the quiet conditions, both SB and control groups achieved a similar degree of scanning accuracy. (Unexpectedly and inexplicably, under the distracting condition, the accuracy of the control group alone deteriorated.) An important point to be noted however, was that the SB groups took longer than the control group to achieve the same level of accuracy, under both quiet and "classroom-like" conditions. Moreover, those with spina bifida and shunted hydrocephalus needed significantly longer than those without shunts to complete the scanning task. On the basis of their results the authors suggested that SB children could perform as accurately as able-bodied children of similar intelligence - if allowed to work at their own pace.

A second measure in this interesting study was the Continuous Performance Test, described by Roswold et al (1965), in which the child listened to a string of letters presented through earphones. The task was to note when a number was presented instead of a letter. On this task, which was not self-paced, the SB groups detected significantly fewer items than the control group. Those with shunted hydrocephalus again tended to perform more poorly than those without shunts.

A further important point on the contribution of intelligence to performance was made by Tew et al (1980) in this study. Using the findings from an earlier report by Stores et al (1978) on inattentiveness, these authors compared the performance on the visual scanning and Continuous Performance Tests of the SB and matched IQ groups with that of Stores' group of average intelligence. Not unexpectedly, in view of previous findings, those of average intelligence performed at a higher level on both tests than those of low average intelligence, irrespective of whether hydrocephalus was present or not. These authors therefore concluded that although "inattention", or the inability to ignore irrelevant information, was often noted in those of lowered intelligence, it did "not appear to be a global characteristic of behaviour among spina bifida children".

In contrast, in their Dutch study investigating memory for new information more directly, Tromp and van den Burg (1982) found that the impaired performance of the hydrocephalic group could not be completely explained by Verbal IQ scores. In this study, 80 children with shunted hydrocephalus, 42 associated with spina bifida, (mean WISC-R Verbal IQ: 86) and 214 matched controls (Verbal IQ:

100) were presented with a taped series of 15 nouns at a rate of 15 words per 25 seconds. Presentation was followed by free recall of the nouns heard. This procedure was repeated four times, giving a total possible score of 75 correctly recalled words. An unexpected recall trial was given after a further 20 minutes of other tests.

Results indicated both impaired immediate and delayed recall in the hydrocephalic group. The delayed recall scores showed that the hydrocephalic children demonstrated a 33% word loss over the twenty minute period compared to 11% for the control group. They also considered that as memory deficit could not be explained by lower intelligence in hydrocephalic children, this should be considered an additional deficit.

In general, little attention has been paid to learning ability in terms of acquisition and retention over time. An exception to this is a well designed small-scale study by Cull and Wyke (1984). This study revealed interesting findings in the learning ability of 10 young (7-9 years) spina bifida children with shunted hydrocephalus (mean IQ:76) compared to an able-bodied group matched on IQ (mean IQ:79) and age (mean age:8 years), and a second able-bodied group also matched on age but of average intelligence (mean IQ:101). The aims of the study were stated as follows:-

(i) To investigate memory function relating to:-

- verbal, non-meaningful information (words)
- verbal, meaningful information (short story)
- non-verbal, non-meaningful information (nonsense shapes)
- non-verbal, meaningful information (faces)

(ii) To analyse the acquisition of information over trials and retention over a period of time.

The procedure for this evaluation of memory function was as follows. In all, retention of verbal and pictorial information was measured on six occasions. For each of the four tests listed above there were three acquisition trials, each immediately followed by a free recall (for verbal information) or recognition (for pictorial information) test (trials 1-3). The amount of material remembered both after a short delay (during which the subsequent learning task was completed) and after twenty-four hours was also assessed by recall or recognition tests (trials 4-5). Following the 24 hour tests, the stimuli were presented once again (reacquisition trial) followed by a final recall or recognition trial (trial 6).

The results were particularly interesting. On all tasks except one, the group of 10 able-bodied children of average intelligence achieved a higher mean number of correct responses than either the 10 SBH children or the able-bodied group matched on IQ. On the Short Story Test, the only significant difference between the three groups was on the 24 hour recall task. Not unexpectedly, in view of previous findings, the SBH children showed significant deficits in their ability "to learn, store and retrieve information" compared to those of average intelligence. In contrast, although mean scores were lower, the SBH group did not show significant deficits in learning and retention compared to the children matched on IQ - except in learning the list of unrelated words.

One important, general finding from this study was that those of below average intelligence were likely to be poorer at retaining new information than those of average intelligence. This supported the results of Tew et al (1980). A more specific finding was that those with spina bifida and hydrocephalus demonstrated a particular deficit in the retention of unrelated words. Cull and Wyke suggested that this discrepancy in verbal learning in the SBH group might be related to the use of inappropriate semantic strategies for encoding verbal information. Thus, when meaningful information was presented, as in a short story, learning was efficient because contextual cues were present. In contrast, the retention of unrelated words depended on the ability to effectively encode information.

The authors put forward the suggestion that the poor performance of the SBH group, compared to children of average or matched intelligence, might have been due to faulty semantic encoding strategies, possibly resulting from hydrocephalic brain damage.

The results of the studies on memory and attentional deficits reviewed above suggest therefore that those with spina bifida and hydrocephalus are likely to demonstrate a general memory impairment. In addition, those with spina bifida and shunted hydrocephalus, often demonstrate a poor ability to filter out irrelevant or redundant information, which may affect task performance or the retention of new information. Furthermore, hydrocephalic brain damage may also selectively affect the ability to use appropriate semantic encoding strategies for the retention of new information.

3. SUMMARY

Over the past twenty-five years the likely sequelae of spina bifida and hydrocephalus have been well documented. It is now clear that the effects of hydrocephalic brain are considerable, ranging across all areas of cognition, but in particular, visual-perceptual motor development and memory are likely to be affected. There would also seem to be differences in cognitive functioning not only between those with and without hydrocephalus, but within the SBH group itself. Three main groups can be distinguished.

Firstly, those with spina bifida only, as a group, have IQs at least within the low average range. Attentional and memory skills are usually consistent with this level of ability although mild deficits in visual-perceptual motor areas are sometimes demonstrated. Some individuals with arrested hydrocephalus may perform at the same level as those with no recorded hydrocephalus, although some may be more accurately classified with those with shunted hydrocephalus.

The second group comprises those with spina bifida and shunted hydrocephalus. In addition to overall intellectual ability just below the average range, this group tends to show a greater discrepancy between verbal and performance skills, demonstrating specific deficit in visual-perceptual motor functioning. The acquisition and retention of new information is also likely to be limited. Those with spina bifida and shunted hydrocephalus of very limited intellectual ability form a third group. This group is comparable to any severely brain-damaged group, demonstrating attentional deficit, memory impairment and poor visual-perceptual motor skills.

These conclusions have important implications when potential for car driving is considered. Two extremes are clear from the descriptions of the three groups above. In Group 1, those with spina bifida alone (and some with arrested hydrocephalus) subject to suitably adapted cars for tuition, may well become drivers. In contrast, those in Group 3, of very limited intellectual ability, cannot be considered potential drivers. In the middle, in Group 2, those with spina bifida and shunted hydrocephalus (and some with arrested hydrocephalus) are a highly variable group, often with specific deficits which might affect driving. This group will therefore be the most difficult to assess.

In the following two chapters, the development of a perceptual-cognitive battery for the assessment of driving related skills in those with spina bifida and hydrocephalus is described.

CHAPTER SEVEN : THE DEVELOPMENT OF THE PERCEPTUAL-COGNITIVE TEST BATTERY FOR DRIVING

In the previous chapters, the problems associated with spina bifida and hydrocephalus have been outlined. One of the main points to emerge was that there are often subtle cognitive deficits which are not well understood and for which there is little known intervention. One of the main purposes of this thesis was to devise a battery of tests which might be used to assess the nature and severity of these deficits, particularly in relation to their possible effects on learning to drive. Before beginning, however, it might be useful to set this work in context by adding an historical note. As previously mentioned, 1976 saw the introduction of Mobility Allowance for those with disabilities affecting walking. This innovation revealed a huge gap in driving assessment facilities for potential rather than experienced drivers. This was particularly evident in my own work with young adults with spina bifida and hydrocephalus.

One of the primary aims of the Mobility Centre was to provide a comprehensive driving ability assessment for those with a physical disability associated with brain damage. This procedure included medical, visual, physical and cognitive assessment, my own part being to devise a suitable perceptual-cognitive assessment for driving.

The work described in this thesis was begun in 1982. At that time, little formal research on brain damage and driving had been reported, with the research findings which were available, mainly focussing on experienced drivers returning to driving after a stroke. Thus, few systematic attempts had been made to predict driving performance on the basis of cognitive and/or perceptual test results. The first objective in this project, therefore, was to develop a battery of tests which might be used to assess the driving potential of young people with congenital cognitive deficits.

Broadly speaking, this battery was developed in three stages. In the first stage, the selection and testing of the first eight items in the battery took place. In the second stage modifications to the battery following the pilot study were undertaken, together with an evaluation of the test performance of 41 subjects. Finally, stage three involved completion of the modified battery by four groups of young people of varying physical and intellectual abilities.

1. STAGE ONE : INITIAL CHOICE OF TEST COMPONENTS

It was seen in earlier chapters that approximately fifty different cognitive tests have been used in studies investigating driving and brain damage. Almost as many different tests have been used to investigate the cognitive deficit of those with spina bifida and hydrocephalus. The choice of the components of the test battery for driving was therefore influenced by two sorts of criteria - the results of studies using specific tests and the psychometric properties of the tests themselves.

This involved a review of the standard clinical tests used in the many studies described in previous chapters eg. the Wechsler Scales, the Frostig Test of Developmental Visual Perception, the Bender-Gestalt Test and the Luria-Nebraska Battery of Neuropsychological Tests (Golden et al, 1980). In addition, comprehensive reviews of clinical tests were consulted (eg. Mittler, 1970; Lezak, 1979) so that unreliable or out-of-date tests could be immediately rejected. Furthermore, although theoretical issues gave precedence, the practical requirements of a working situation were also considered - the tests should be short and motivating, simple to administer, require little equipment and be easy to interpret.

Using these criteria, very few of the tests used in previous studies appeared suitable to use in a battery to assess driving potential. However, several reliable, well-established tests from the WAIS (Picture Arrangement, Picture Completion and Digit Span Tests) were retained and a further five tests (Token Test, Letter Cancellation, Road Map Test, Logical Memory and Visual Reproduction Tests) chosen as fulfilling the criteria listed above. Table 14 lists the eight tests selected together with a brief description of the processes each was thought to assess. A more detailed description of the rationale, presentation and scoring of each test then follows.

TEST	PROCESSES ASSESSED
GENERAL INTELLECTUAL LEVEL	
1.Token Test	Verbal comprehension
2.Picture Arrangement	Logical reasoning and planning
VISUAL-PERCEPTUAL SKILL	
3.Picture Completion	Visual discrimination
4.Letter Cancellation	Visual scanning
5.Road Map Test	Directional orientation
MEMORY AND ATTENTION	
6.Digit Span	Auditory verbal attention
7.Logical Memory	Auditory verbal memory
8.Visual Reproduction	Visual memory

TABLE 14 : Initial test items of the perceptual-cognitive battery for driving.

2. DESCRIPTION OF TEST COMPONENTS

2.1. TESTS OF GENERAL INTELLECTUAL LEVEL

(i) TOKEN TEST (De Renzi and Vignolo, 1962)

The aim of this test is to detect disrupted linguistic or symbolic processes (Lezak, 1979). The complete form consists of 62 items designed to tap basic concepts of size, colour and location. The items are divided into five sections of increasing complexity, ranging from "Touch the red circle" in Part I to "Touch the rectangles slowly and the circles quickly" in Part V. The test materials are twenty tokens in two shapes - circles and rectangles; two sizes - big and small; and five colours - red, yellow, blue, green and white.

The long form of the test comprising 62 items is generally used to detect severe language disturbances (eg. De Renzi and Vignolo, 1962), but shortened versions have been shown to be adequate for screening purposes ie. to eliminate the possibility of significant language defects (Boller and Vignolo, 1966; Spellacy and Spreen, 1969).

Although the SBH groups considered in this thesis were unlikely to show severe language disturbances (Tew and Laurence, 1979), it was decided to include 6 items from Part V of the Token Test as a screening measure of the ability to understand and follow instructions.

The items chosen are shown in Table 15. Items 1-4 were chosen as representing direct choices of colour and position; Item 5 involved a repetitive motor response to a two-part instruction; and Item 6 required left-right discrimination for successful completion.

TEST PRESENTATION : Six large circles were placed in a row on a table, with the following instructions - "Tell me the colour of each circle". The six large rectangles were then placed above the circles with the explanation - "There are rectangles in the same colours. I am going to give you some instructions to follow". The instructions for the 6 items in Table 15 were then given individually.

TEST SCORING : Each item was scored correct or incorrect with a maximum error score of 6.

TEST ITEMS
1. Put the red circle on the green rectangle.
2. Put the white circle behind the yellow circle.
3. Touch the blue circle with the red rectangle.
4. Put the white circle in front of the blue rectangle.
5. Touch the rectangles slowly and the circles quickly.
6. Touch the white circle without using your right hand.

TABLE 15 : Items from the Token Test.

(ii) PICTURE ARRANGEMENT TEST (Wechsler, 1981)

This WAIS-R subtest is considered to measure logical reasoning, planning and the understanding of cause-effect relationships. The test consists of 10 sets of cartoon pictures (3-6 cards per set), each depicting a story. Each set is presented in a scrambled order with instructions to rearrange them to make a story.

This test was found by McFie (1960) to be vulnerable to brain injury, particularly right-sided lesions. Sivak et al (1981) also found a positive correlation (r=.46) between Picture Arrangement scores and the driving of 23 individuals with brain damage. As personal clinical experience with young SBH adults has demonstrated a consistent difficulty in completing the last few items, only 8 of the 10 sets of cards were presented.

TEST PRESENTATION : The cards for the first item were placed in presentation order from left to right on a table. The following instructions were given:- "These pictures tell the story of a man building a house, but they are in the wrong order. Please put them in the right order to tell the story". Sixty seconds were allowed for rearrangement of the pictures. If incorrect, the correct arrangement was shown, following which a second attempt was allowed. Whether correct or not, Item 2 was then presented as follows:- "I am not going to tell you the story for these pictures. Please work out the story and rearrange the pictures to show the story". If unsuccessful, the correct arrangement was shown and a second attempt allowed. On subsequent items only one attempt was allowed, the test being discontinued after failure on three consecutive items.

TEST SCORING : Four points were given for correct solutions within 60 seconds. Two points were allowed for solutions on the second attempt for Items 1 and 2. For Item 8, a correct solution within 25 seconds scored 6 points and within 25-40 seconds, 5 points. The maximum number of points for this test was therefore 34.

2.2. TESTS OF VISUAL-PERCEPTUAL SKILL

(i) PICTURE COMPLETION TEST (Wechsler, 1981)

This revised version of the WAIS (Wechsler, 1956) subtest is considered to assess perceptual discrimination, visual recognition, visual organisation and general reasoning ability (Lezak, 1979). The test involves noting the missing parts of 20 incomplete pictures of human features, common objects or scenes.

Cohen (1957) considered the original test to be the non-verbal equivalent of the WAIS Comprehension subtest. Lezak (1979) found it particularly resistant to the effects of brain damage. As mentioned in the third chapter, Sivak at al (1981), investigating cognitive test scores and driving performance in a brain-damaged group, found a positive correlation (r=.72) between a short form of this test and driving ability. In the present battery all 20 items were presented.

TEST PRESENTATION : The test was introduced as follows:- "I am going to show you pictures which have an important part missing. Please tell me which part is missing in each picture". The first picture (a door without a handle) was shown, with the question - "What is missing?" Twenty seconds were allowed for the answer. If the missing part was not noted, the missing handle was pointed out - "Look the door has no handle". Items 2-20 were presented without further help. Twenty seconds were allowed for each item.

TEST SCORING : A score of 1 was given for each item correct, giving a maximum score of 20.

(ii) LETTER CANCELLATION TEST

This test requires "visual selectivity at fast speed on a repetitive motor response task" (Lezak, 1979). The basic format is rows of letters randomly interspersed with target letters (E,F) to be crossed out (Figure 5).

Diller et al (1974) found that with stroke patients, failure appeared to be associated with spatial neglect problems in those with right hemisphere lesions and with difficulties in the temporal processing of information in left hemisphere patients.

B	E	I	F	H	F	E	G	I	C	H	E	I	C	B	D	F	C	H	F	B	E	D	A	C	A	F	C	I	H	C	F
E	B	A	F	E	A	C	F	C	H	B	D	C	F	G	C	A	H	E	F	A	C	D	C	F	E	H	B	F	C	A	D
E	H	A	E	I	E	G	D	E	G	H	B	C	A	G	C	I	E	H	C	I	E	F	H	I	C	D	B	C	G	F	D
E	B	C	A	F	C	B	E	H	F	A	E	F	E	G	C	H	D	E	H	B	A	E	G	D	A	C	E	E	E	B	A
E	G	D	C	D	A	F	C	B	I	F	E	A	C	D	B	E	E	D	G	A	C	E	E	F	B	C	A	F	E	A	B
F	C	H	D	E	F	C	G	A	C	B	E	C	D	F	H	E	H	E	F	D	I	C	H	E	I	E	B	C	A	H	C
D	B	A	C	B	G	B	I	E	H	A	E	A	F	C	I	C	A	B	E	G	F	B	F	B	A	E	A	B	G	C	G
F	A	C	D	B	E	B	C	H	F	E	A	D	H	C	A	I	E	E	B	H	D	C	A	G	D	E	A	F	E	B	E
I	G	C	E	D	A	C	H	D	E	D	C	A	B	A	E	F	B	C	F	D	A	C	G	B	E	H	C	D	F	E	H

FIGURE 5 : E F Letter Cancellation Test.

TEST PRESENTATION : The printed sheet of letters was placed on the table and the task explained as follows - "Please go along each row of letters crossing out all the Es and Fs (Demonstration). Work as quickly as you can but try not to miss out any letters."

TEST SCORING : The number of letters omitted and the time for completion were noted. Maximum error score : 88.

(iii) ROAD MAP TEST (Money et al, 1965)

The Road Map Test is a test of directional orientation. A route is followed on a simplified street map, stating whether the turns made are to the left or the right (Figure 6). The original test contained 32 turns, the second 16 requiring mental rotation. To identify simple left-right confusions, only the first 16 turns were included in this battery.

TEST PRESENTATION : Instructions were as follows:- " Please follow this route (indicating line) on the map, saying at each corner whether you turn left or right. Keep the map this way up at all times."

TEST SCORING : Each correctly named turn was scored 1. Maximum score : 16.

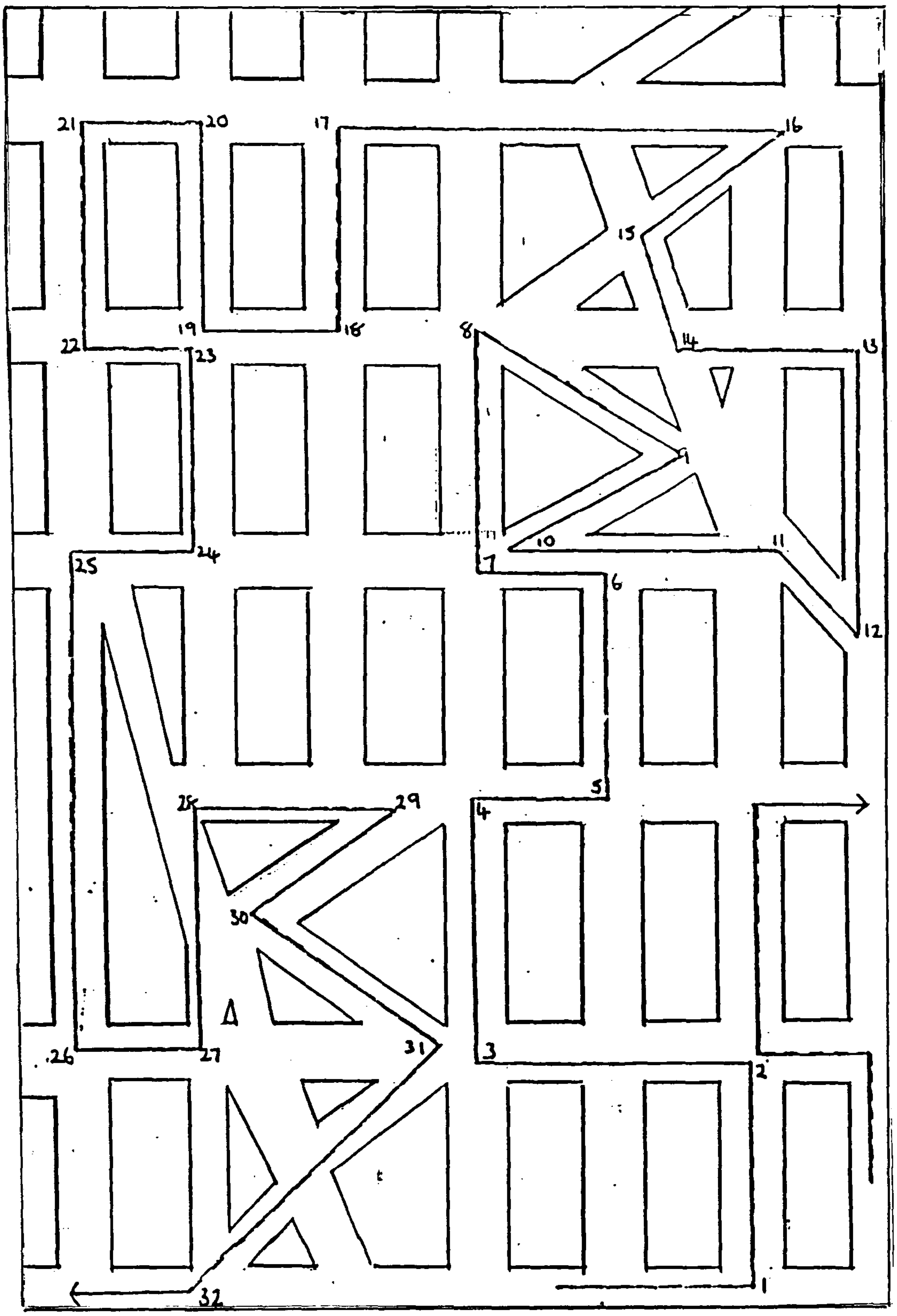


FIGURE 6 : Road Map Test of Directional Orientation (Money et al, 1965).

2.3. TESTS OF MEMORY AND ATTENTION

(i) DIGIT SPAN TEST (Wechsler, 1956)

This WAIS subtest is considered to assess immediate memory, attention and mental double tracking (Lezak, 1979). It involves repeating strings of digits forwards (3-9 digits) and backwards (2-8 digits).

Costa (1975) noted that a disparity in favour of digits forwards was frequently seen in brain-damaged individuals with concentration problems. Perhaps because it has both memory and attention components, the Digit Span Test has been found to be sensitive to the effects of traumatic brain damage (Lezak, 1979).

TEST PRESENTATION : The test was introduced as follows:- "I am going to say some numbers. When I have finished please repeat them in the same order as you heard them". A practice string of 3 digits was given followed by the first string of 3 numbers. If repeated correctly a string of 4 digits was given. If repeated incorrectly a second 3 digit string was given. If two strings of equal length were incorrectly repeated the test was discontinued. The strings of digits increased to 9.

For the reverse order digits the instructions were:- "When I have said the numbers please say them backwards - starting from the end". Several simple practice items were given to ensure that the task was understood. If the task was not understood Lezak's suggestion for further practice was used ie. a 2 digit string was tried and a 3 digit string of consecutive numbers eg. 1-2-3. The procedure for digits forwards was followed for digits backwards, up to 8 digits if appropriate.

TEST SCORING : The total score was the sum of the digit length repeated forwards and that repeated backwards. Maximum score : 17.

(ii) LOGICAL MEMORY TEST (Wechsler, 1945)
This test is part of the Wechsler Memory Scale. It was designed to assess immediate recall of logical information, when the amount to be processed is more than can be fully retained. Two paragraphs are read with time after each reading for immediate free recall.

TEST PRESENTATION : Instructions were as follows :- "I am going to read a short story. Please try to remember as much as you can so that you can retell the story. You do not have to repeat the story, but can use your own words". The first story was read and recalled and then the same procedure was used for the second story.

TEST SCORING : A score of 1 was given for each relevant part of the stories recalled, the total score being halved.

As the first story contained 24 memory units and the second 22, the highest possible score was 23.

(iii) VISUAL REPRODUCTION TEST (Wechsler, 1945)

This subtest of the Wechsler Memory Scale was designed to assess visual memory for shapes. The shapes are black line drawings presented on a white card. On Cards 1 and 2 there is a single shape, whilst on Card 3 there are two shapes. Each card is presented for 10 seconds.

TEST PRESENTATION : Instructions for Cards 1 and 2 were as follows: - "I am going to put a card in front of you. Please look at the shape drawn on the card and try to remember it. When I take the card away, draw the shape here" (indicating the place on the paper). For Card 3, which shows two shapes, the instructions were :- "The next card shows two shapes. Try to remember both in 10 seconds. Please draw them next to each other at the bottom of the page".

TEST SCORING : Wechsler's scoring allows 3 points for Figure 1, 5 for Figure 2 and three for each of the shapes on Card 3. Maximum score : 14.

3. PILOT TESTING OF THE BATTERY

Once the choice of test items had been made according to the criteria set, the next step was to try the tests with a group of young SBH adults. For this first part of the pilot study, 32 subjects (Ss) were asked to complete the eight tests described above as part of a Driving Ability Assessment at Banstead Mobility Centre (Appendix IV). This took place over a nine month period.

3.1. SAMPLE DESCRIPTION

All 32 Ss (21 males, 11 females) had spina bifida myelomeningocele and hydrocephalus. Twenty-five had shunted hydrocephalus and 7 arrested hydrocephalus. The mean age of the males was 17yrs 9mths (range: 15-23yrs) and the females 17ys 11mths (range: 15-21yrs).

3.2. PROCEDURE

Ss were tested individually according to the instructions outlined in the previous section.

3.3. RESULTS

At this stage, test items were examined qualitatively and quantitatively. Items were considered qualitatively to see whether they were interesting and motivating and to consider the spread of scores produced. Score distributions were considered by quantitative examination of the test data. Sex differences in cognitive functioning were also considered at this stage, as earlier work at Banstead Mobility Centre had indicated that not only did more males present for assessment, but that males were more likely to become drivers than females.

3.3.1. QUALITATIVE OBSERVATIONS

TOKEN TEST : As expected, the majority of Ss found no difficulty following the six verbal instructions of this test. Moreover, for the few Ss who did demonstrate difficulties, confusion only emerged in the later items. For example, when attempting to follow the instructions for Item 5 (Touch the rectangles slowly and the circles quickly), one common response was to touch single rectangles and circles alternately, thus losing the difference in speed between "slow" and "fast". In contrast, some Ss touched one rectangle slowly, followed by one circle quickly and considered the task completed.

PICTURE ARRANGEMENT TEST : Many Ss found this task difficult, even on the simplest items. Intuitively, incorrect sequencing of the pictures to make a logical story more often seemed to result from poor understanding of cause-effect relationships rather than inaccurate interpretation of individual pictures.

PICTURE COMPLETION TEST : Many Ss also found difficulty with this task. A major error was to name a non-essential feature as the missing item. For example, one item depicted a tilted jug, full of water. Although, the level of water was at the lip of the jug, no water was shown to be falling into the glass below. The correct missing feature was the water pouring from the jug, but a common (and perhaps not unreasonable) response was that nobody was holding the jug!

LETTER CANCELLATION TEST : A high and generally consistent level of accuracy was seen in the identification and crossing out of the target letters on the matrix. In contrast, the time taken to complete the task varied. The major factor affecting task completion time appeared to be level of fine motor co-ordination and pencil control, rather than scanning time. This is in keeping with the Greater London Study results for tests of manual skills (Carr et al, 1983). Describing the performamce of SBH and control groups at 11 years, on the WISC Coding Tests, Carr and her colleagues reported that although low IQ often had a detrimental effect on drawing times, the major difficulty appeared to be one of manual co-ordination.

ROAD MAP TEST : Given unlimited time, most Ss could distinguish the left from the right turns on this simple map. However, as this test was not timed, scores do not reflect the hesitancy shown by many subjects.

DIGIT SPAN TEST : Whereas repeating digits forward was adequately completed by many Ss, difficulties were commonly noted in the digits backwards section. A common response was to reverse the last two digits eg. for 629, 962 instead of 926.

LOGICAL MEMORY TEST : Results on this test clearly demonstrated the inability of the SBH group to easily absorb and reproduce new information. Many Ss could only remember a few relevant points for each story, whilst others produced longer but inaccurate stories.

VISUAL REPRODUCTION TEST : Poor performance also characterised this test of memory for shapes. For singly presented shapes, errors often reflected poor attention to detail or spatial disorganisation eg. lines were not at right angles. For Item 3, involving two shapes, either one shape alone was drawn as only one had been learnt; or neither shape was remembered accurately if the learning time had been divided between the two shapes. Poor pencil control undoubtedly contributed to poor performance on this test, although Ss were carefully watched to assess this during the drawing of the shapes.

In summary, this qualitative analysis suggested at least some sensitivity to differences between individuals.

3.3.2. QUANTITATIVE ANALYSIS OF DATA

The quantitative data were examined for two reasons. Firstly, to look at score distribution and item sensitivity. Secondly, to consider whether there were differences in cognitive functioning between males and females.

TEST SCORE MEANS, RANGE AND DISTRIBUTION

The means and standard deviations (SD) for each of the eight tests are given in Table 16. The Wechsler norms for the four tests, which remained in their original form (Picture Completion, Digit Span, Logical Memory and Visual Reproduction) are also given to allow comparisons to be made with an able-bodied population.

Comparisons between the Wechsler norms and the SBH group's mean scores on the Picture Completion Test and the three memory tests indicated that the SBH group scored below or just within the average range. Very poor performance was also demonstrated on the Picture Arrangement Test, for which the mean score of 15.6 was less than half the maximum possible score of 34. As can be seen from Table 16, very few Ss made errors on the Token Test, Letter Cancellation Test and the Road Map Test.

The range of test scores on most items was fairly wide and showed a normal distribution curve on the Picture Arrangement, Picture Completion, Digit Span, Logical Memory, Visual Reproduction and Letter Cancellation (time) Tests. Figure 7 shows the distribution of scores for all 32 Ss on each of the 8 test items (9 measures).

TEST*	SBH GROUP n=32			WECHSLER NORMS
	Mean	SD	Max.	
1.TOKEN TEST(errors)	.78	1.58	0	-
2.PICTURE ARRANGEMENT	15.63	6.05	34	-
3.PICTURE COMPLETION	10.16	3.43	20	14±4
4.LETTER CANCELLATION				
(a) no. of errors	1.41	2.60	0	-
(b) time in secs.	140.50	33.4	-	-
5.ROAD MAP TEST	13.22	2.98	14	-
6.DIGIT SPAN TEST	9.88	1.95	17	11±4
7.LOGICAL MEMORY TEST	6.47	3.93	23	10±3
8.VISUAL REPRODUCTION	6.44	3.20	14	11±3

TABLE 16 : Mean raw scores, standard deviations (SD) and maximum possible score on the perceptual-cognitive test battery. *High scores indicate good performance except on Token and Letter Cancellation Tests.

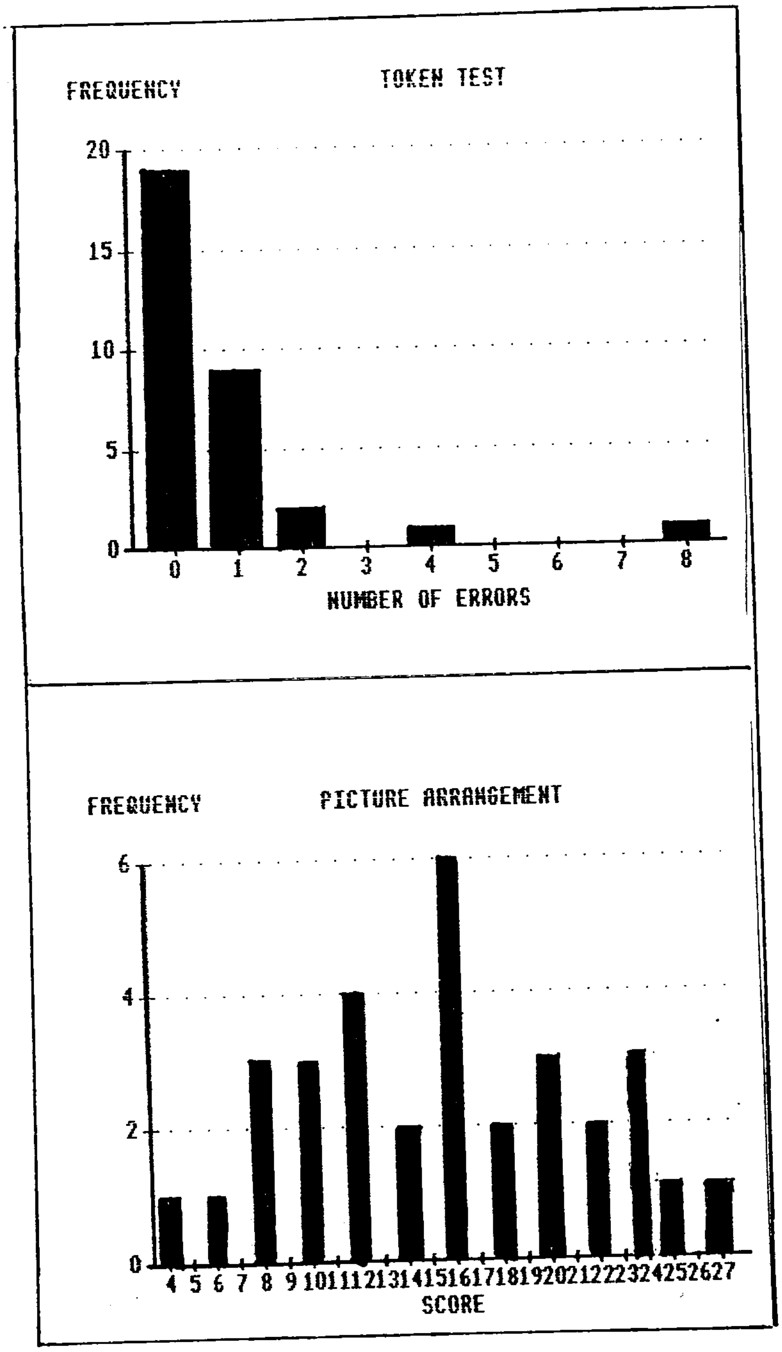


FIGURE 7 : Distribution of test scores on perceptual-cognitive battery for 32 SBH subjects (cond).

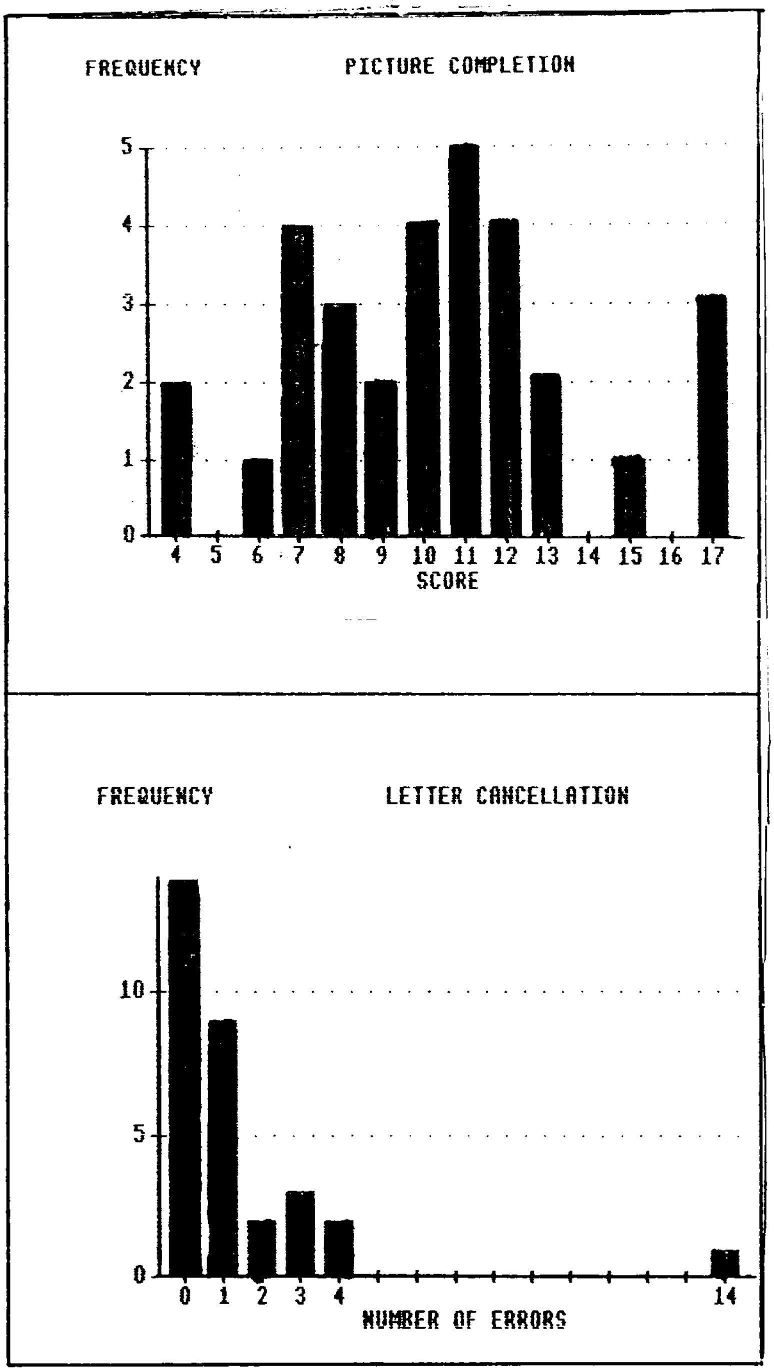


FIGURE 7 : Distribution of test scores on perceptual-cognitive battery for 32 SBH subjects (cond).

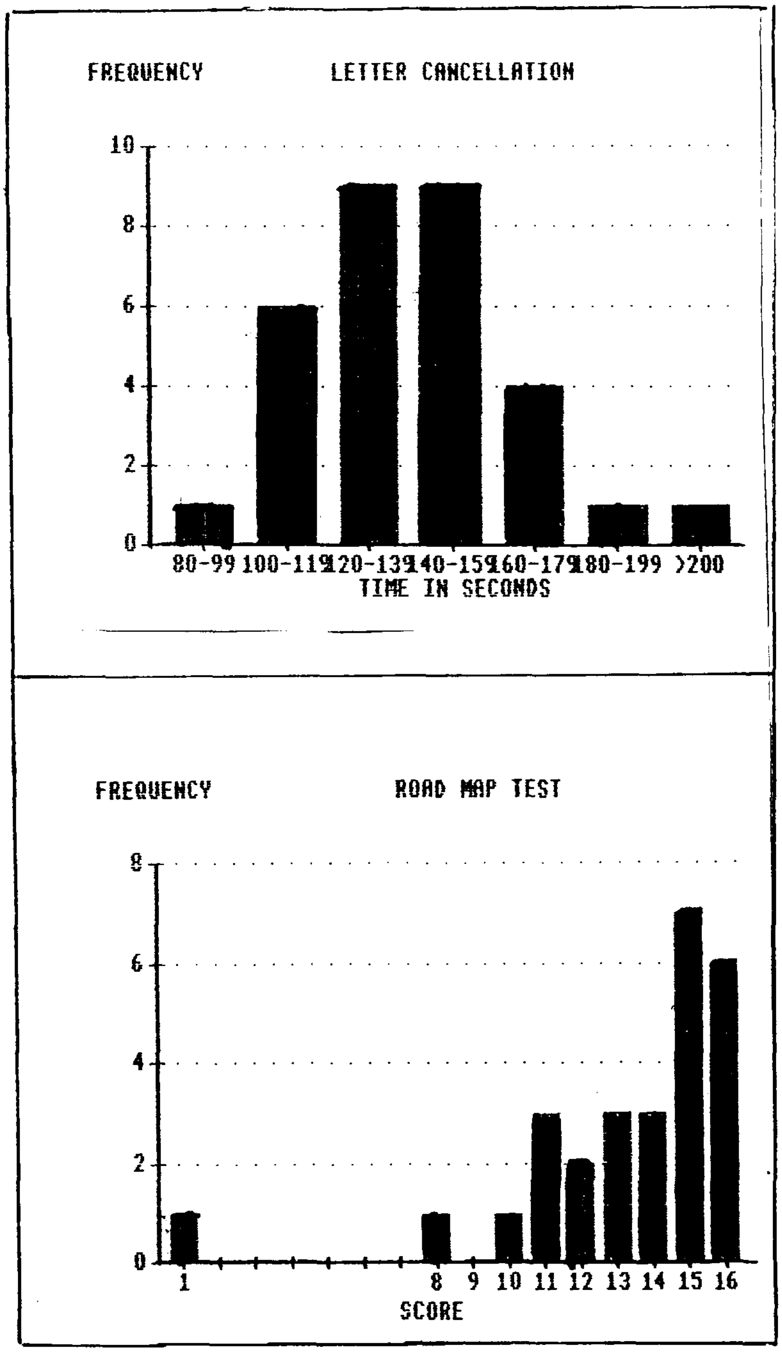


FIGURE 7 : Distribution of test scores on perceptual-cognitive battery for 32 SBH subjects (cond).

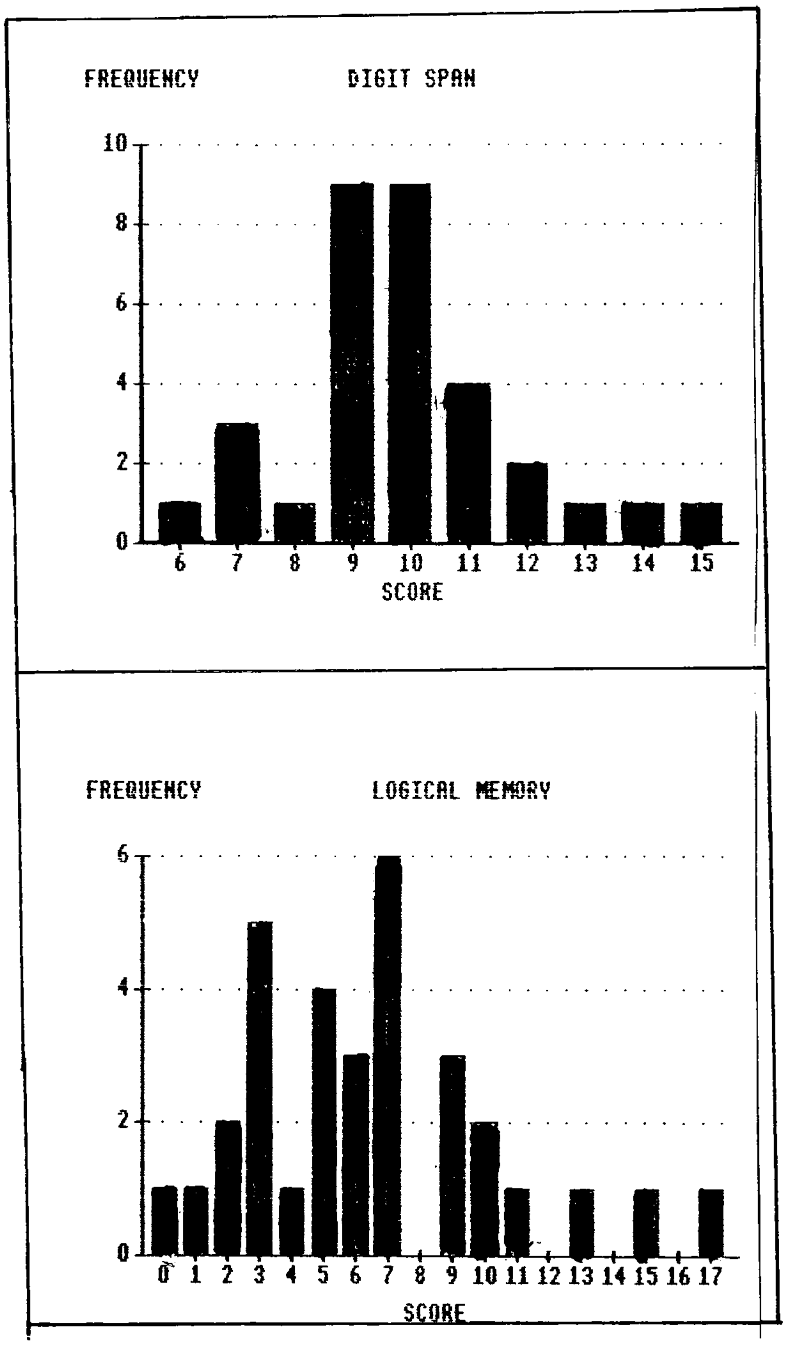


FIGURE 7 : Distribution of test scores on perceptual-cognitive battery for 32 SBH subjects (cond).

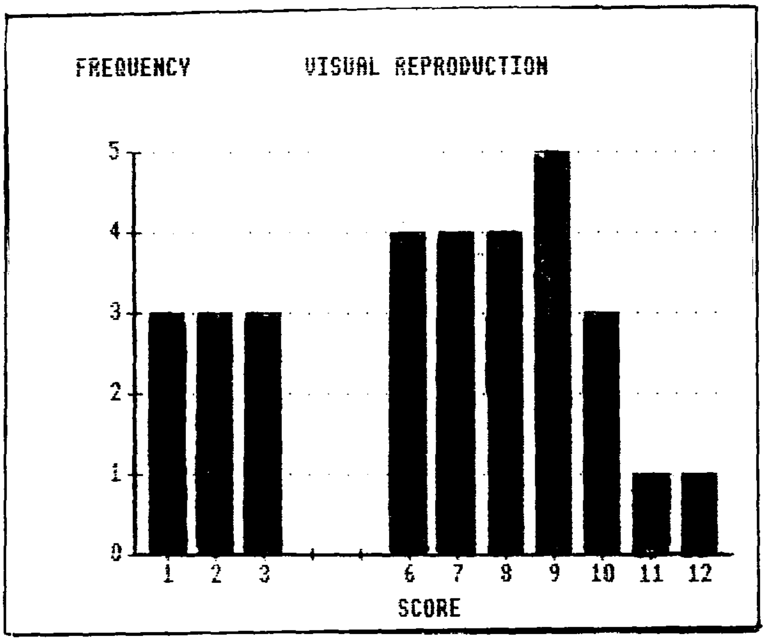


FIGURE 7 : Distribution of test scores on perceptual-cognitive battery for 32 SBH subjects.

On three measures, Token Test, Letter Cancellation Error Score and the Road Map Test, few errors were made. The question to be considered here was - did these tests contribute sufficient information for them to be retained in the battery? These three tests are considered further in the section on test modifications.

SEX DIFFERENCES

Although the studies reviewed earlier had provided no evidence of sex differences in cognitive functioning, as clinical experience indicated that more males than females were likely to become drivers, it seemed sensible to check that no differences were present for this group. As can be seen from Table 17, although the females in the sample scored marginally better than the males on all tests except Picture Arrangement, the results of Analyses of Variance comparing the scores for each test, indicated that these differences were not statistically significant. In view of these findings, it was not thought necessary to consider sex differences in the test development any further.

TEST*	MALES n=21	FEMALES n=11
TOKEN TEST	1.05	.27
PICTURE ARRANGEMENT	16.48	14.90
PICTURE COMPLETION	9.86	10.73
LETTER CANCELLATION		
(a) no. of errors	1.80	.73
(b) time in secs	140.30	140.80
ROAD MAP TEST	13.41	13.00
DIGIT SPAN TEST	9.90	9.81
LOGICAL MEMORY TEST	5.86	7.73
VISUAL REPRODUCTION	6.35	6.64

TABLE 17 : Mean raw scores of males and females on the perceptual-cognitive battery. *High scores indicate good performance except on Token and Letter Cancellation Tests.

4. STAGE TWO : ADDITIONS TO THE BATTERY

The assessment of 32 young people described in the previous sections took place over a period of nine months. Their results, together with my own clinical evaluation of the tests, raised two main issues for consideration in the next phase of the test development. In view of the limited range of scores shown on three tests, the Token Test, Letter Cancellation Error Score and the Road Map Test, their value needed to be carefully assessed. A second important issue was whether the range of cognitive processes sampled by the eight tests adequately covered the skills likely to be relevant for driving.

4.1. THE TESTS WITH A LIMITED RANGE OF SCORES

The Token Test, Letter Cancellation and Road Map Tests each presented slightly different problems.

TOKEN TEST : As most people completed this test without difficulty, the main problem to be considered was lack of sensitivity. However, because this test came first, it had the advantage of being a non-stressful introduction to the battery. Moreover, for the few who did have difficulty following instructions, the test served as an indicator of potential difficulties for other tests. It was therefore considered a useful test to retain.

LETTER CANCELLATION TEST : There was really only one component of this test which required consideration, as most subjects had a very low error score. However, as the time taken to complete the test was highly discriminating, the test was considered useful to retain for this measure. Furthermore, as speed of information processing is, on the face of it, a critical element in driving, it seemed premature to reject the test on accuracy scores alone.

ROAD MAP TEST : Although few of the group demonstrated severe left-right confusions, observations on how each subject approached the task seemed to provide information which might be useful during the tuition period. For example, some seemed hesitant making decisions or unfamiliar with using a map. This test also had a certain amount of face validity for driving, not present in other tests in the battery.

Taking these various points into consideration, it was decided to retain these three tests in the battery.

4.2. ADDITIONAL VISUAL-PERCEPTUAL MOTOR TESTS

In the course of the first series of tests, my own increasing knowledge of the driving literature highlighted the fact that visual-perceptual motor aspects of cognitive functioning were not adequately covered in the battery. For this reason, three additional tests sampling visual-perceptual motor processes were considered for inclusion in an amended battery. These tests were designed to investigate visual-motor ability (Pattern Copying Test, MacQuarrie (1953)), figure-ground discrimination (Embedded Figures Test, Witkin et al (1971)) and visual tracking (Line Tracing Test). These tests also fulfilled the practical criteria for inclusion in the battery, outlined in the last chapter, in that they were easy to administer and score. The test rationale, presentation and scoring for each test are described in this section.

(i) PATTERN COPYING TEST

This is one of seven tests comprising the MacQuarrie Test for Mechanical Ability (MacQuarrie, 1953) and closely resembles the section of the Frostig Test, devised to measure "spatial" ability. In comparison with the shape copying from memory on the Visual Reproduction Test, this test involves copying a shape onto a dot matrix.

As the norms available relate to jobs of a mechanical nature and in most cases consider scores for the MacQuarrie Test as a whole, there was some doubt concerning their value for the SBH group under consideration.

The original test included 20 shapes, each to be copied onto a small 5x5 matrix. To minimise the known fine motor-cordination difficulties of the SBH group, an enlarged set of 4 shapes and 4 matrices were used (Figure 8).

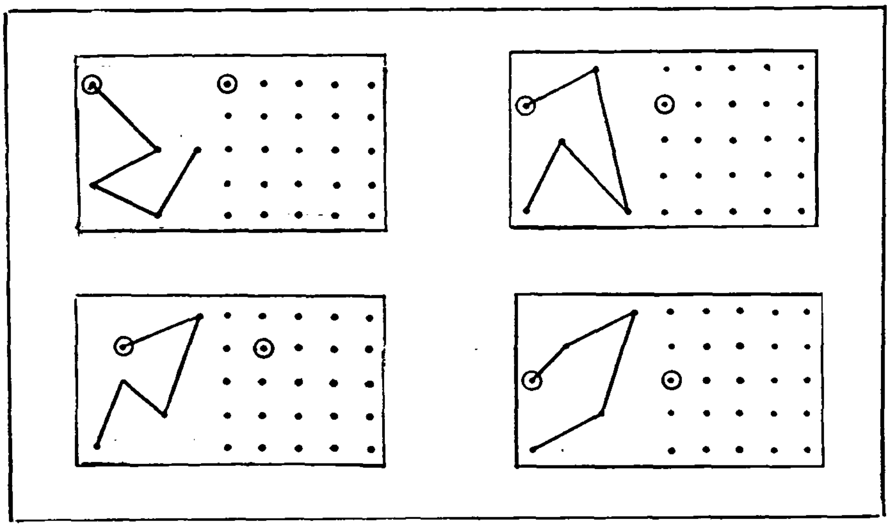


FIGURE 8 : Pattern Copying Test (original size) from MacQuarrie, 1953.

TEST PRESENTATION : The set of shapes was placed on the table with the following instructions - "Please copy each shape onto these dots, trying to make your drawing exactly the same as the one you are copying. Start on the circled dot here (indicate dot). Each line should begin and end on a dot." Additional explanation or demonstration was given if necessary.

TEST SCORING : For each shape, each line correctly placed on the matrix was scored 1. Maximum score : 16.

(ii) EMBEDDED FIGURES TEST (Witkin et al, 1971)

This test was designed to assess competence at perceptual disembedding ie. the ability to break up an organised visual field. The task is to locate a simple figure within a larger complex figure. Witkin et al (1971) found this test correlated well with "social behaviour, attitudes, body concept and personality".

The original test involved remembering the shape to be located and allowed up to three minutes for the completion of each item. For this study, for the identification of severe figure-ground discrimination deficit, the simpler practice section of the Group Embedded Figures Test was chosen for inclusion in the battery.

TEST PRESENTATION : A sheet of paper with 7 complex figures and 7 simple figures was placed on the table with the following instructions - "Look at Number 1 (indicate simple shape). Can you find the T shape here? (Indicate complex shape.) When you find the shape draw round the outline like this (demonstrate). Now try Number 2". Similar instructions were given for Numbers 3 - 7. (Examples of the simple and complex shapes are given in Figure 9.)

TEST SCORING : 1 point was scored for the correct identification of figures for Numbers 2-7, Number 1 being considered a practice item. Maximum score : 6.

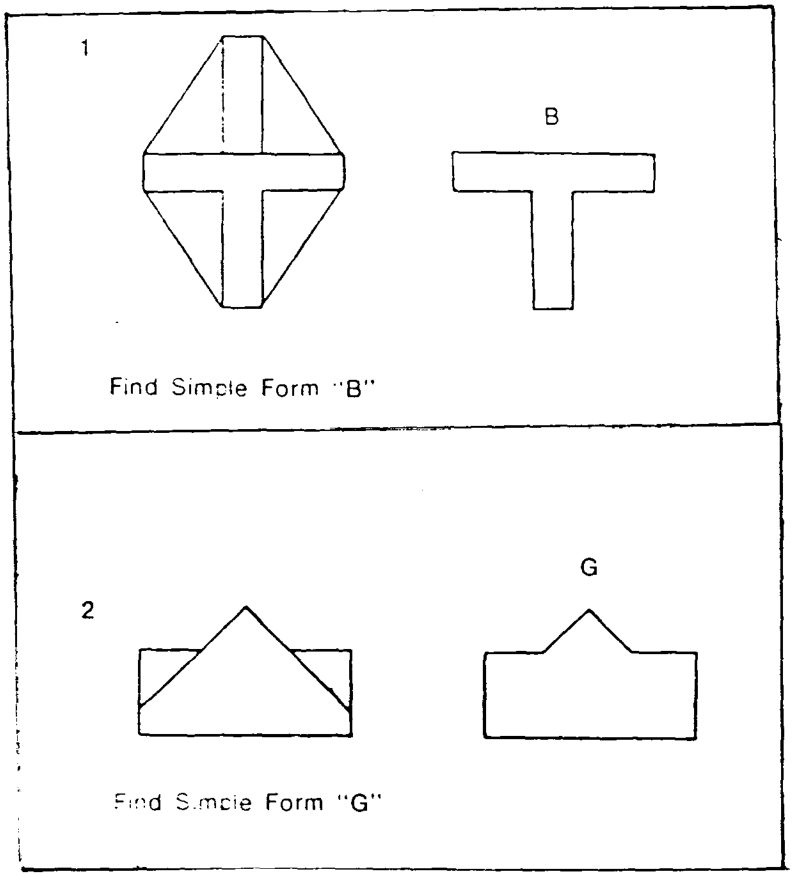


FIGURE 9 : Embedded Figures Test adapted from Witkin et al, 1971.

LINE TRACING TEST

This visual tracking task consists of a tangled line pattern numbered at each end of each line (Figure 10). The task is to visually track each line from the left to the right. Rey (1964) found that on a similar task, 75% of an adult population averaged 4 seconds per line, time increasing with age. Ninety percent of adults made no errors. Lezak (1979) considered that long response times, more than a few errors or frequent false starts might be signs of serious perceptual or visual-motor problems. In comparison to the Letter Cancellation Test, this test does not involve the use of a pencil and therefore poor performance on the basis of poor manual co-ordination can be excluded.

TEST PRESENTATION : A practice sheet was presented showing 8 lines simply intertwined. The instructions were - "Look at the line which starts at Number 1 here (indicate).

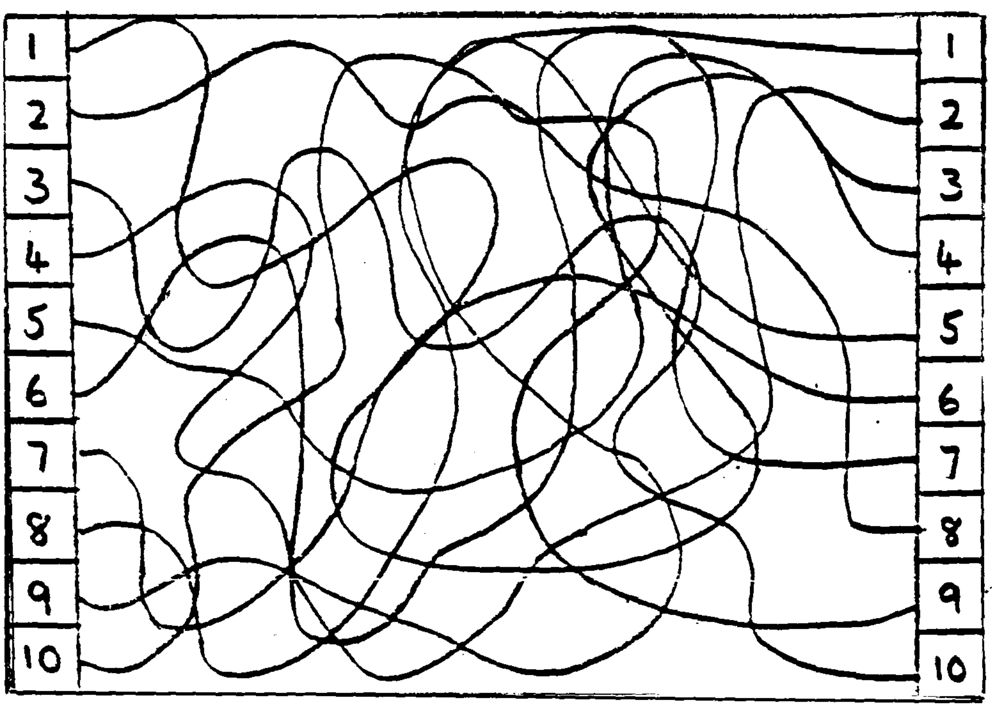


FIGURE 10 : Line Tracing Test.

Follow the line with your eyes only, not using your finger, and say which number the line finishes at on the right hand side". Examples were given until the task was correctly performed. Instructions for the test sheet of 10 lines were then given - "Now do the same with these lines - follow each one from left to right using your eyes only. Work as quickly as you can". Ss completed as many items as possible in forty-five seconds.

TEST SCORING : 1 point was scored for each line correctly followed within 45 seconds. Maximum score : 10.

5. ANALYSIS AND EVALUATION OF THE MODIFIED BATTERY

The next stage in the test development was to evaluate the expanded battery of 11 tests. For this, a second series of SBH adults, attending for a Driving Ability Assessment over a fifteen month period, completed the modified test battery.

5.1. DESCRIPTION OF THE SAMPLE

The 41 Ss all had spina bifida myelomeningocele and hydrocephalus. At the time of assessment, the mean age of the 18 males was 18 years 6 months (range: 16-23 years) and the 23 females 17 years 10 months (range: 15-25 years).

5.2. PROCEDURE

As before, all Ss were tested individually according to the instructions outlined previously.

5.3. RESULTS

5.3.1. QUALITATIVE DATA

No differences were noted in the approach to and completion of the 8 tests in the original battery between the series of 32 Ss, described in the previous section and this series of 41 Ss.

The following observations were made on the three new tasks.

PATTERN COPYING TEST : Many Ss scored very poorly on this task. When copying the shape onto the matrix, although the general direction of the line was often followed, errors were commonly noted in the length of line and the angle subtended. Most Ss knew their attempts were inaccurate, but were unable to correct them.

EMBEDDED FIGURES TEST : This task did not present difficulties for most Ss. Where there were errors, these were often, surprisingly, on an early item, Item 3; or on Items 6 and 7, when the bisecting lines of the complex shape were often included in the outline drawing of the target figure.

LINE TRACING TEST : All Ss were able to complete the practice items without difficulty. On the main task, difficulty seemed due to an inability to deal with the more complex intertwining of lines. Within the 45 seconds allowed, often no more than 6 items were completed, some of these being incorrect.

5.3.2. QUANTITATIVE DATA

The formal data analysis is presented in two parts. In the first part, the means, range and distribution of scores on the three additional visual-perceptual motor tests are examined. In the second part of this section, a comparision is made between scores on the eight common tests in the battery for the two series of SBH adults. This comparison was considered to be important in view of the wide range of scores demonstrated by the SBH groups in the studies reviewed in the previous chapter eg. Tew and Laurence, 1975.

MEANS, RANGE AND DISTRIBUTION OF SCORES ON THE THREE ADDITIONAL TESTS : Table 18 lists the means and range of scores for the Pattern Copying, Embedded Figures and Line Tracing Tests. The wide range and distribution of scores reflected the differing abilities of the Ss and the potential of these tests to discriminate between those with and without visual-perceptual motor deficit (Figure 11).

TEST	MEAN	RANGE
PATTERN COPYING TEST	5.28	0-16
EMBEDDED FIGURES TEST	4.76	0-6
LINE TRACING TEST	4.34	0-7

TABLE 18 : Mean scores for 41 SBH adults on the 3 additional tests of the modified battery.

TEST*	GROUP 1 (n=32)		GROUP 2 (n=41)		F+
	Mean	Range	Mean	Range	
1.TOKEN TEST	.78	0-8	.57	0-4	.10
2.PICTURE ARRANGEMENT	15.60	4-27	15.22	4-26	.06
3.PICTURE COMPLETION	10.15	4-17	9.73	4-16	3.95
4.LETTER CANCELLATION					
(a) no. of errors	1.42	0-14	1.55	0-9	.13
(b) time in secs.	140.48	97-280	139.26	78-280	.04
5.ROAD MAP TEST	13.24	1-16	13.33	8-16	.20
6.DIGIT SPAN TEST	9.88	6-15	10.34	6-15	.15
7.LOGICAL MEMORY TEST	6.47	0-17	6.67	0-13	1.23
8.VISUAL REPRODUCTION	6.45	1-12	6.49	2-11	.01

TABLE 19 : Mean scores for two SBH series (Groups 1 and 2) on eight tests. * High scores indicate good performance except on Token and Letter Cancellation Tests. + All F values insignificant, except for Picture Completion ($p<.05$).

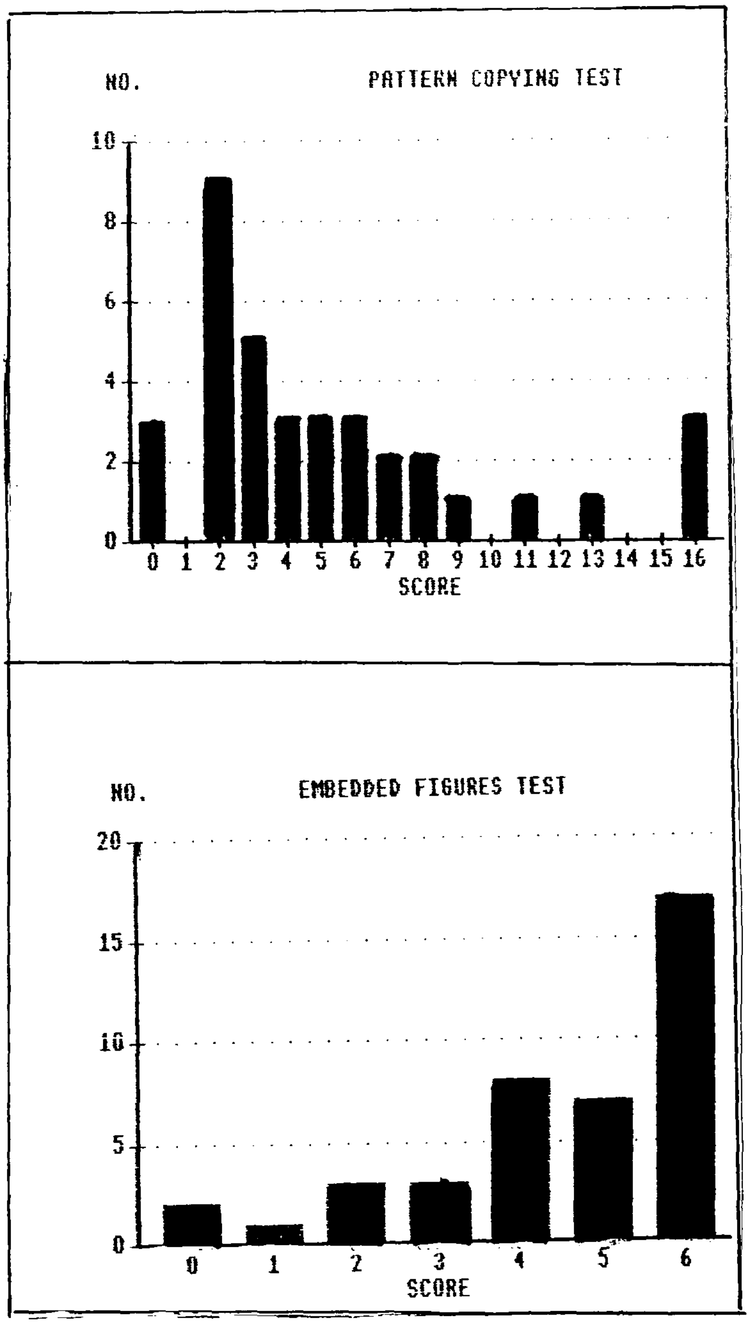


FIGURE 11 : Distribution of test scores on Pattern Copying, Embedded Figures and Line Tracing Tests for 41 SBH subjects (cond).

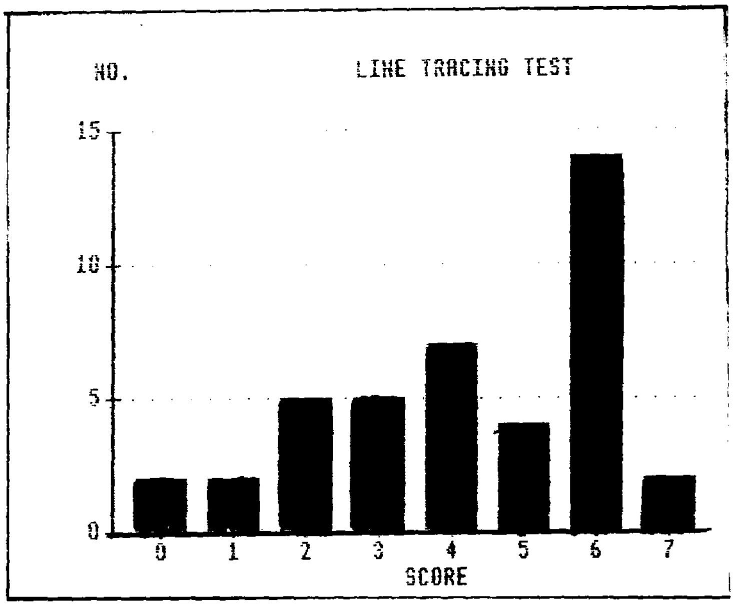


FIGURE 11 : Distribution of test scores on Pattern Copying, Embedded Figures and Line Tracing Tests for 41 SBH subjects.

COMPARISON OF THE TWO SBH SAMPLES : The mean scores on the 8 tests for the two samples are shown in Table 19. The distribution of scores for each test is shown in Figure 12. Statistical analysis of these score distributions using One Way Analysis of Variance indicated that of the eight tests, only the scores on the Picture Completion Test showed a significant difference between the two groups.

Having established that the two series of SBH adults were from the same population, further analyses on the

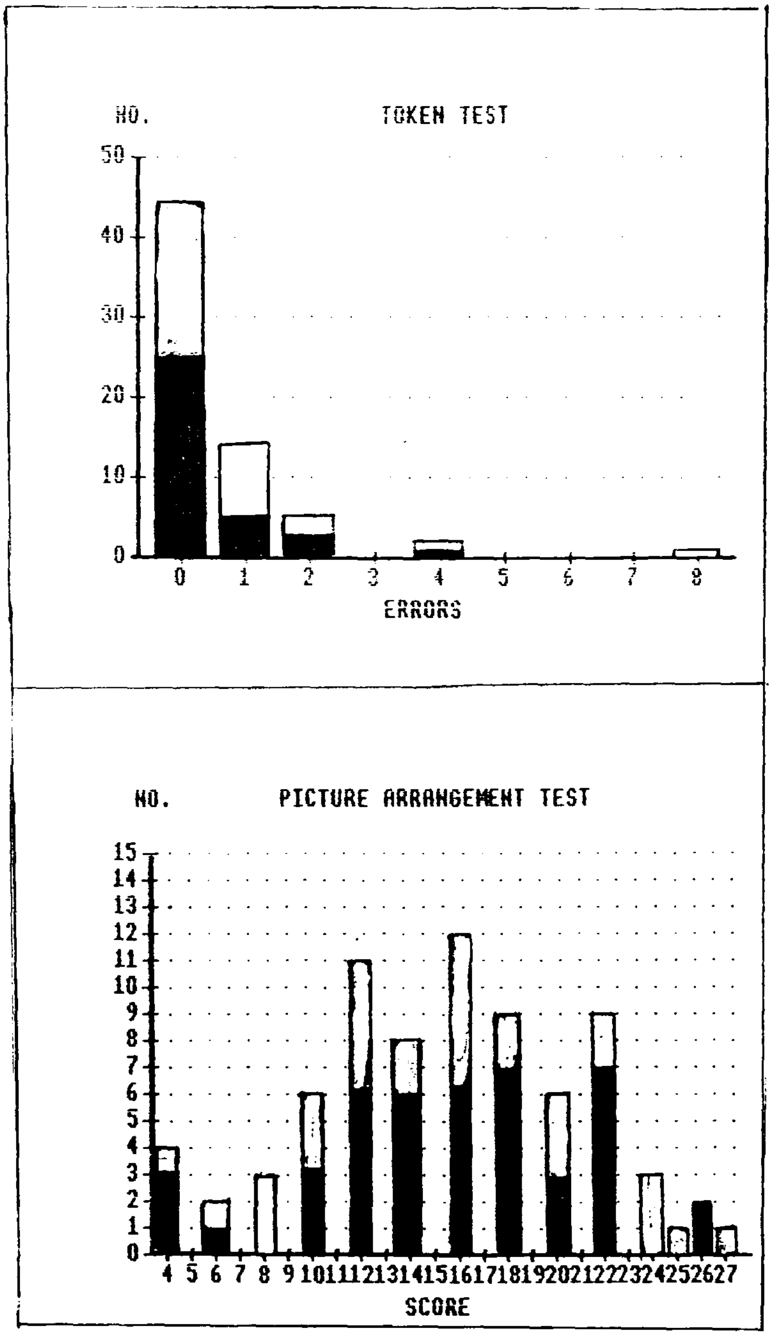


FIGURE 12 : Distribution of test scores on perceptual-cognitive battery for two SBH groups (cond).

Group 1 (N=32) Group 2 (N=41)

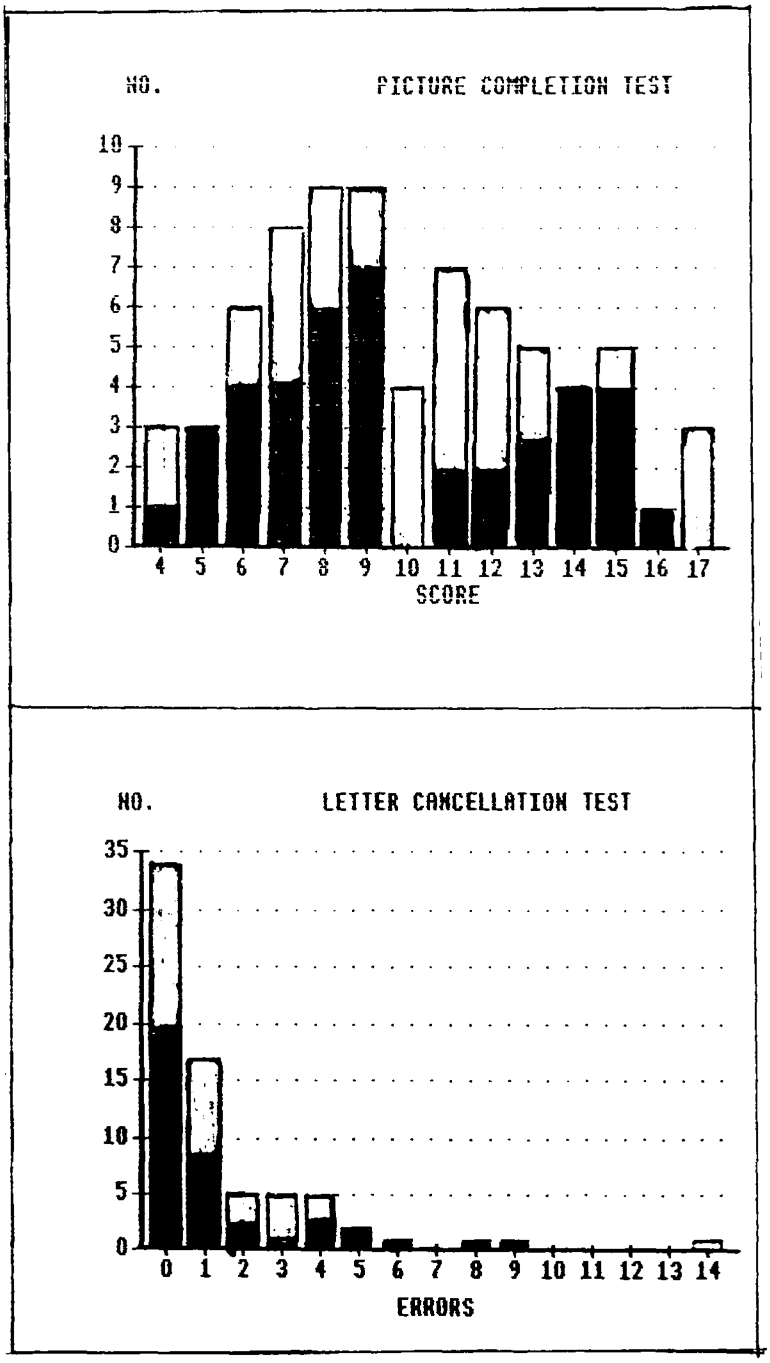


FIGURE 12 : Distribution of scores on perceptual-cognitive battery for two SBH groups (cond).

Group 1 (N=32) Group 2 (N=41)

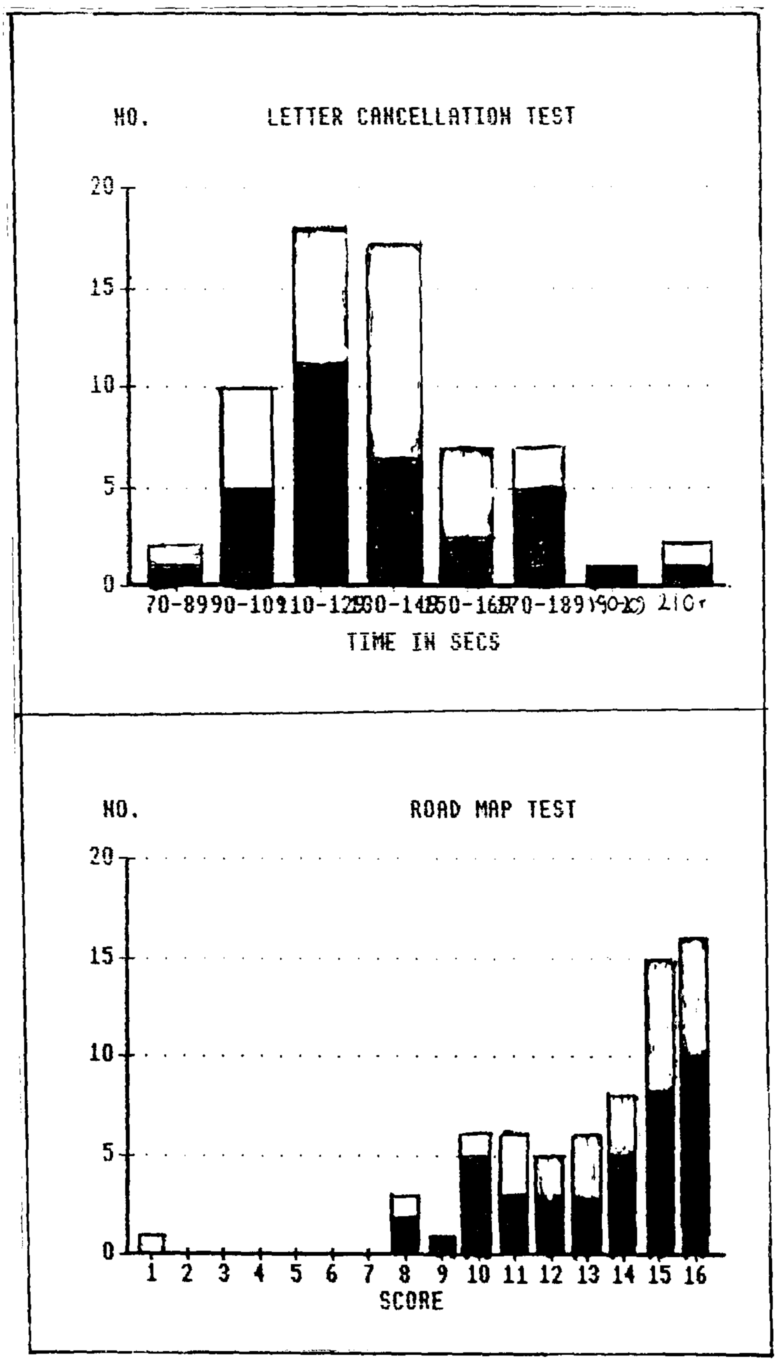


FIGURE 12 : Distribution of test scores on percetual-cognitive battery for two SBH groups (cond).

Group 1 (N=32) Group 2 (N=41)

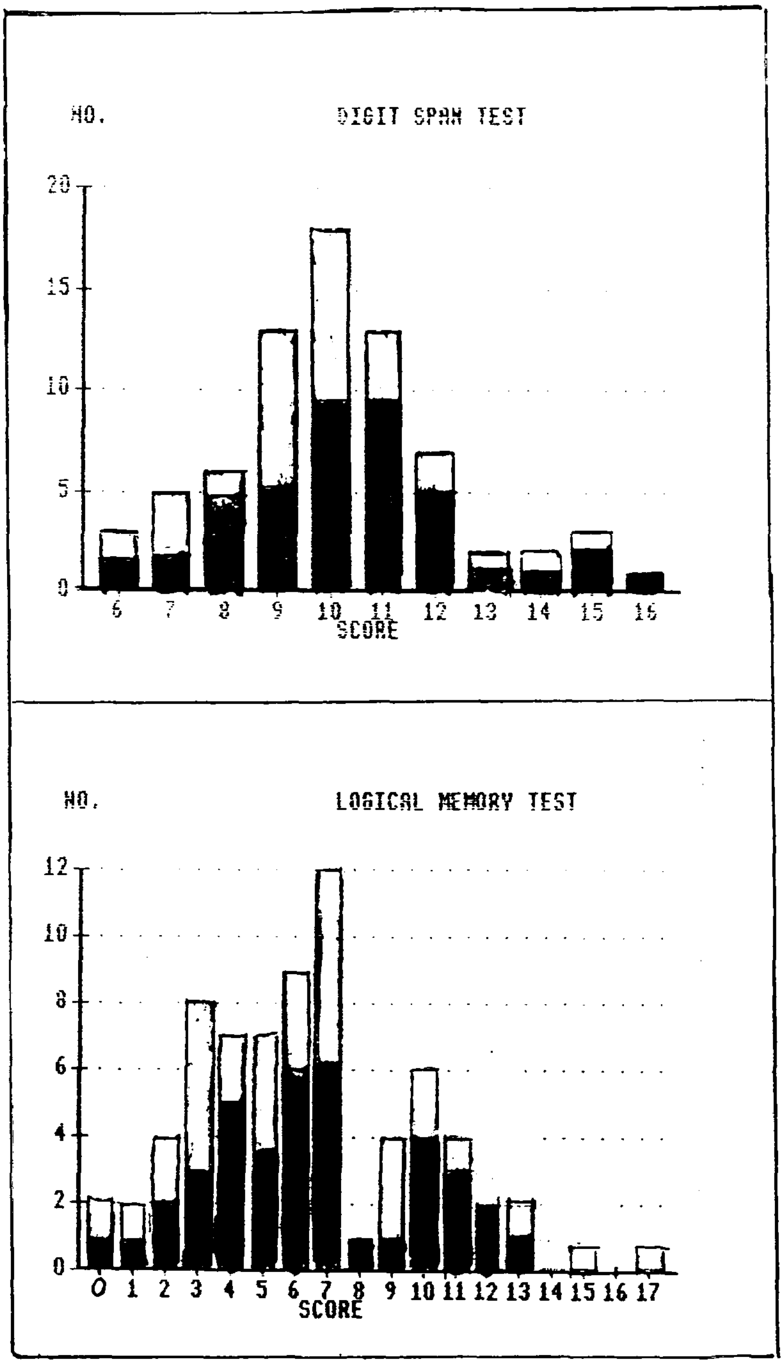


FIGURE 12 : Distribution of test scores on perceptual-cognitive battery for two SBH groups (cond).

Group 1 (N=32) Group 2 (N=41)

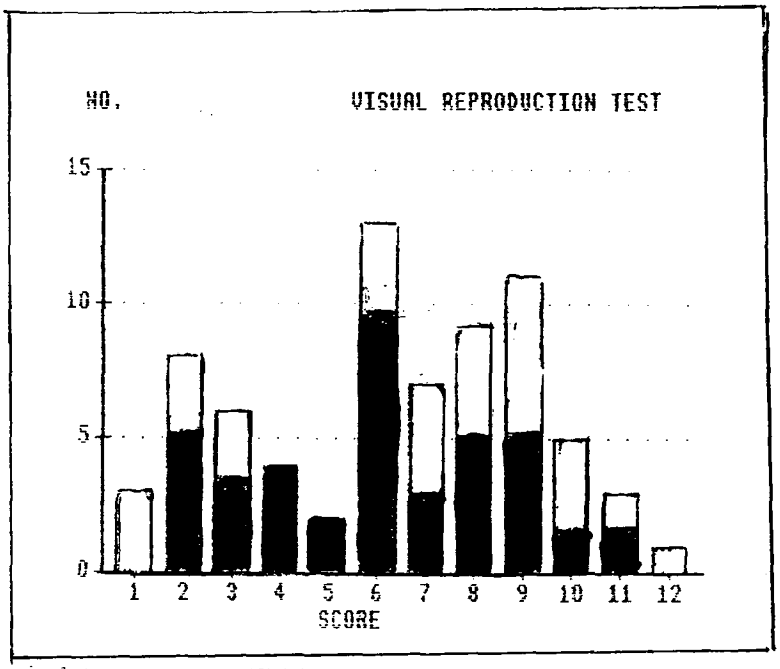


FIGURE 12 : Distribution of test scores on perceptual-cognitive battery for two SBH groups.

Group 1 (N=32) Group 2 (N=41)

predictive nature of the test battery, described in the following chapter, were able to be planned.

5.4. SUMMARY

Results from the inspection and analysis of test scores, presented in the foregoing sections, fit well with the profile of the cognitive abilities of children and adolescents with spina bifida and hydrocephalus, described in earlier chapters. Although there were marked differences between the abilities of some individuals, as a group, the cognitive profile of young SBH adults can tentatively be summarised as follows:-

(i) GENERAL INTELLECTUAL LEVEL : The ability to understand and follow instructions was adequate. In contrast, non-verbal reasoning ability was limited, as measured by the Picture Arrangement Test.

(ii) VISUAL-PERCEPTUAL MOTOR SKILL : Visual discrimination, as assessed by the ability to note the missing part of a picture (Picture Completion Test) was poor. Although scanning and tracking skills were generally accurate, they were nevertheless slow. Although poor fine motor co-ordination might have slowed down progress on the Letter Cancellation and Pattern Copying Tests, both of which required the use of a pencil, an alternative explanation is that rate of search might be a more sensitive measure of visual-perceptual or cognitive disability than accuracy. On the Road Map Test, right-left orientation was generally intact but again time was needed for decisions to be made.

(iii) MEMORY AND ATTENTION : Memory for digits was just within the average range but retention of a story (verbal presentation) and shapes (visual presentation) was well below average compared to test norms for the general population.

So far, these results seem to support the idea that a perceptual-cognitive battery might be a useful tool in the assessment of driving potential in those with spina bifida and hydrocephalus.

6. STAGE THREE : TEST PERFORMANCE OF 4 MATCHED GROUPS

So far, we have considered the sensitivity of 11 test items to differences within the SBH group. The group of subjects focussed on in this thesis fall between the populations generally studied, children and adults. Consequently there is still relatively little data on the general cognitive functioning of young adults with spina bifida, with or without hydrocephalus. In this stage of the project, therefore, a subsidiary objective, not directly relevant to the prediction of driving ability, was pursued. It was considered that data could easily be made available to further explore the nature of cognitive functioning in young adults with and without brain damage. In particular it would be interesting to examine the extent to which the tests differentiated not only between the main groups of spina bifida only and spina bifida with hydrocephalus, but also between SB and able-bodied groups and SB and cerebral palsied (CP) individuals.

Three comparisons were of interest. Firstly, do those with spina bifida only perform at the same level as their able-bodied peers? Secondly, are there differences between SB groups with and without hydrocephalus? Thirdly, are there differences between the CP and SBH groups, both of whom have known brain damage? On the basis of the results of research reported earlier, it was expected that performance on tests would deteriorate across groups in the following order:- able-bodied, spina bifida only, spina bifida with hydrocephalus, cerebral palsy.

6.1. DESCRIPTION OF THE SAMPLE

Seventy-six young people participated in this part of the study - 19 able-bodied (AB), 19 with spina bifida only (SB), 19 with spina bifida with hydrocephalus (SBH) and 19 with cerebral palsy (CP). All were attending school or college, the majority following non-examination or pre-vocational courses.

All four groups of Ss were individually matched on chronological age and sex. There were 5 males and 14 females in each group, ages ranging from 16-18 years (Table 20).

GROUP	MEAN AGE	RANGE
Able-Bodied	17yrs 0mths	16yrs 6mths- 17yrs 7mths
Spina Bifida only	16yrs 10mths	16yrs 2mths- 17yrs 10mths
SB/Hydrocephalus	17yrs 2mths	16yrs 4mths- 17yrs 10mths
Cerebral Palsy	17yrs 0mths	16yrs 0mths- 17yrs 11mths

TABLE 20 : Mean age and range of ages of four groups of 19 Ss matched on sex and age.

6.2. PROCEDURE

All Ss completed the 11 tests individually according to the instructions described previously.

6.3. ANALYSIS AND EVALUATION OF RESULTS

The data for the four groups of Ss are summarised in Table 21 and shown graphically in Figure 13. As can be seen, despite the small groups, there was a consistent pattern of findings. In nearly all cases, the pattern of scores for the tests was as predicted, with the able-bodied group performing better than the SB only group, followed by those with spina bifida and hydrocephalus. The CP group performed worse of all. However, statistical analysis of this data revealed that differences between the mean scores of the groups were reliable for only six tests (as

TEST	AB	SB	SBH	CP	F	p
TOKEN TEST	.74	.32	.56	.94	2.25	ns
PICTURE ARRANGEMENT	22.16	19.89	14.95	11.06	1.91	ns
PICTURE COMPLETION	11.68	11.78	10.68	9.00	9.45	.001
LETTER CANCELLATION						
(a) no. of errors	1.16	.79	1.05	3.78	2.04	ns
(b) time in secs.	100.21	105.06	141.16	176.11	9.98	.001
ROAD MAP TEST	12.32	13.95	12.63	11.53	2.23	ns
PATTERN COPYING	9.68	7.73	5.00	4.76	5.58	.01
EMBEDDED FIGURES	6.00	5.42	5.32	4.94	3.80	.025
LINE TRACING	6.37	5.21	4.47	3.39	7.70	.001
DIGIT SPAN	10.16	10.47	10.21	9.00	1.86	ns
LOGICAL MEMORY	7.42	8.56	7.72	6.88	.61	ns
VIS.REPRODUCTION	8.68	8.05	7.05	5.50	3.42	.025

TABLE 21: Mean test scores of 4 matched groups, able-bodied (AB), spina bifida only (SB), spina bifida with hydrocephalus (SBH) and cerebral palsy (CP) on the perceptual-cognitive battery.

*p<.001 **p<.01 ***p<.025

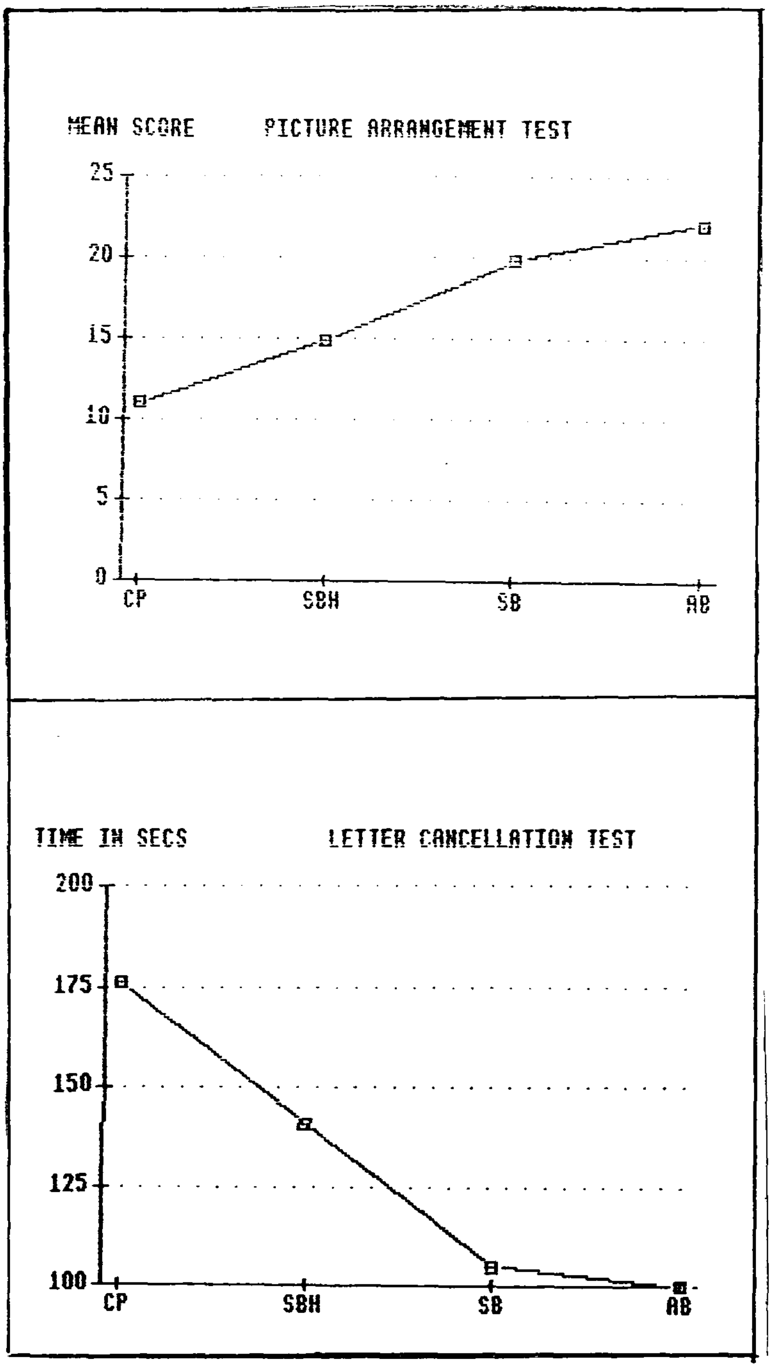


FIGURE 13(a) and 13 (b) : Mean scores of 4 matched groups on Picture Arrangement and Letter Cancellation Time Tests.

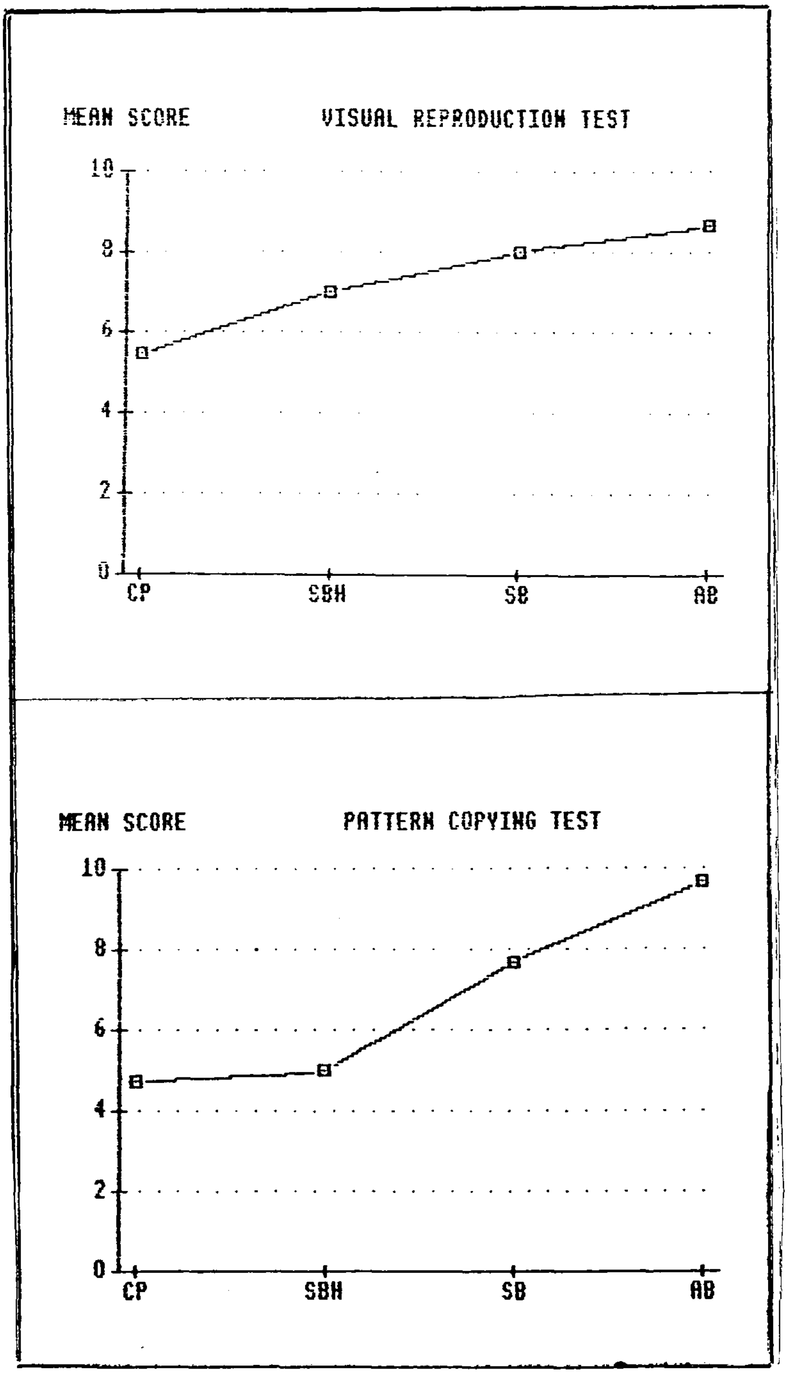


FIGURE 13(c) and (d) : Mean test scores for 4 matched groups on the Visual reproduction and Pattern Copying Tests.

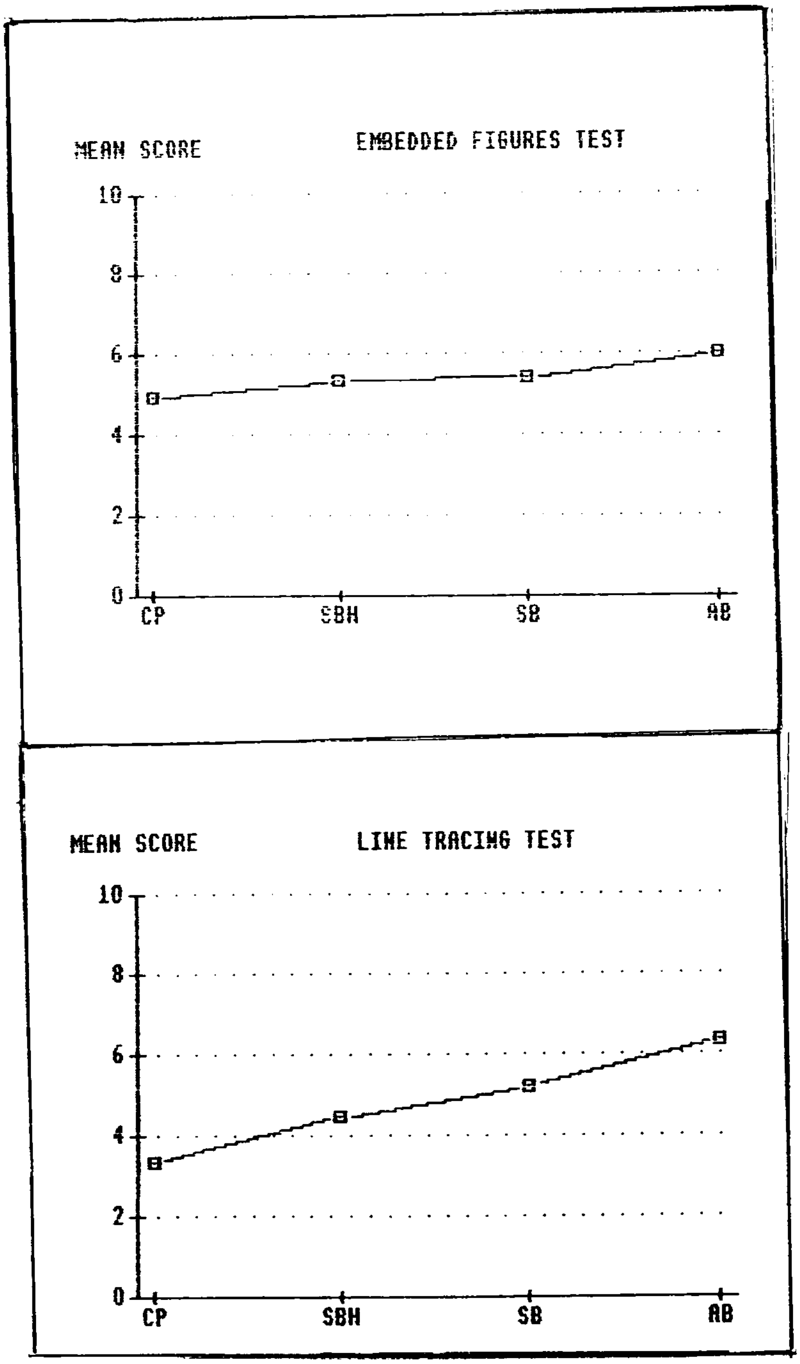


FIGURE 13 (e) and (f) : Mean test scores for 4 matched groups on the Embedded Figures and Line tracing Tests.

indicated by the F values given in Table 21). These 6 tests were Picture Arrangement, Letter Cancellation Time, Pattern Copying, Embedded Figures, Line Tracing and Visual Reproduction Tests.

To further investigate the nature of the significant differences between the four groups on these six tests, post hoc comparisons (Tukey, 1953) were made. The results of these tests are discussed in the section following, which considers three sets of group comparisons - able-bodied versus SB only, spina bifida with and without hydrocephalus and finally, SBH versus CP groups.

6.3.1. ABLE-BODIED VERSUS SPINA BIFIDA ONLY GROUP

Within the literature on spina bifida and spina bifida with hydrocephalus, there is a clear suggestion that those with SB only are not, as might be expected, equal to their able-bodied peers (eg. Tew and Laurence, 1975). Although there may be no known brain damage, it is often thought that the slightly lower scores may be attributable to very mild and undiagnosed hydrocephalus. However, in general, these statements are based on overall IQ scores rather than specific tests of the type used in this study. It was therefore interesting to examine the pattern of results for the able-bodied and SB only groups.

The AB group only performed better than the SB group on 6 of the 12 measures. These were the Picture Arrangement, Letter Cancellation Time, Pattern Copying, Embedded Figures, Line Tracing and Visual Reproduction Tests. It is however to be noted that, apart from the Picture Arrangement and Line Tracing Tests, on all tests which did not require the use of a pencil, the SB group performed at or above the level of the AB group. However there were times when this might have been due to ceiling effects for the AB group. For example, all AB Ss scored full marks on the Embedded Figures Test.

As far as statistically significant differences are concerned, post hoc tests revealed that the only significant difference between the AB and SB only groups was on the Line Tracing Test ($p<.001$). Overall, therefore, these results provide only marginal support for the notion that those with SB only are consistently poorer than their able-bodied peers.

6.3.2. SPINA BIFIDA GROUPS WITH AND WITHOUT HYDROCEPHALUS

At the level of group comparisons, the literature on the cognitive functioning of the various groups within the spina bifida complex, very clearly indicates the adverse affects of hydrocephalus on intellectual development. At the same time, all studies which have obtained marked differences between SB only and SBH groups have noted the extensive variation within groups (eg. Stephen, 1963;

Badell-Ribera, 1966 and Tew and Laurence, 1975).

In this small study, inspection of the mean scores of the SB and SBH groups, suggests a consistent superiority of the SB over the SBH group. Post hoc tests, however, revealed that none of these differences were statistically significant. It is not easy to account for this rather unexpected finding, except to note that it may well be a function of the wide range of abilities seen within these groups. As the numbers in each group in this study were relatively small, this means that group differences have to be large to reach statistical significance.

6.3.3. SPINA BIFIDA WITH HYDROCEPHALUS VERSUS CEREBRAL PALSY GROUPS

Although it is clear from Table 21 that the SBH and CP groups consistently performed at a lower level than the AB and SB groups, it is also evident that the CP group was considerably more impaired than its SBH peer group. Statistically, this difference was only significant for scores on the Line Tracing Test. Again, for the CP group with more impaired co-ordination than the SBH group, particularly poor performance was noted on the Letter Cancellation and Visual Reproduction Tests.

Of most significance from the scores of the SBH and CP groups was confirmation of previous findings that damage to the brain, from whatever origin, results in impaired cognitive functioning.

6.4. SUMMARY

It is clear from the findings outlined above, that some tests in this battery are more sensitive to the abilities of different groups than others. The failure to find a marked difference in functioning between the AB and SB only groups is of particular interest. One possible explanation is that the delay noted in studies with SB children was due to restricted environmental experiences. By early adulthood, the SB group may have caught up with their able-bodied peers. A second point is the fact that the two brain-damaged groups, those with SB and hydrocephalus and those with cerebral palsy, performed at a consistently lower level than either the SB only or the AB groups. This finding confirms that the SBH group focussed on in this thesis, may need help in many areas of learning. However, the overlap of scores between SB and SBH subjects also indicates that caution needs to be shown when predicting performance from cognitive tests.

Central to this thesis is the notion of predictive validity for driving. The next chapter, therefore, considers in detail the predictive validity for driving of individual tests and groups of tests from this perceptual-cognitive battery.

CHAPTER EIGHT : THE STRUCTURE OF THE TEST BATTERY AND ITS PREDICTIVE VALIDITY

In the previous chapter, the focus of attention was on the 11 individual tests which made up the proposed battery. Evaluation of the battery primarily considered the adequacy of the score distribution yielded by each item and the sensitivity of each one to differences between able-bodied and disabled groups. Although not all items were as satisfactory as had been hoped in discriminating between these groups, it was decided to proceed to the main objective of the study - an analysis of the predictive validity of the battery of tests.

As discussed in Chapter Three, the extent of the relationship between clinically measured cognitive deficit and driving performance has been inconclusive. All except one of studies considered (Sivak et al, 1981) were only able to demonstrate relationships between specific tests and off-road manoeuvres (eg. Van Zomeren et al, 1988; Schweitzer et al, 1988). In addition, nearly all the subjects in these studies were experienced drivers returning to driving after disability. The subject population in this thesis was rather different in that all were nondrivers when the clinical cognitive tests were completed. A second major difference was the criteria for driving success. In this part of the study, the criteria for success was passing the standard Department of Transport Driving Test. This was, therefore, an objective, but global, measure of driving proficiency, in contrast to the greater specificity of the off-road measures mentioned earlier.

The purpose of this part of the study is twofold. Firstly, the factor structure of the battery is examined to see if and how the various tests are grouped together. Secondly, its predictive validity for driving is considered.

1. FACTOR STRUCTURE OF THE TEST BATTERY

1.1. DESCRIPTION OF THE SAMPLE

The Ss were the 4 groups of 19 subjects ie. able-bodied, spina bifida, spina bifida with hydrocephalus and cerebral palsy, and the 32 SBH subjects who completed the modified battery. (These Ss are described in detail in Chapter Seven.)

1.2. RESULTS

As scale scores were not available for eight of the eleven tests, raw scores were used for the calculation of the intercorrelations. Table 22 shows the Pearson's product-moment correlations between the twelve measures

	TT	PArr	PCom	LCEr	LCT	RMT	PCop	EFT	LTra	DSp	LMem	VisR
TT	1.00											
PArr	-.15	1.00										
PCom	-.17	.56*	1.00									
LCEr	-.24	.28	.22	1.00								
LCT	-.21	.46	.44	.35	1.00							
RMT	-.34	.55*	.56*	.31	.53*	1.00						
PCop	.27	-.34	-.20	-.26	-.31	-.30	1.00					
EFT	.09	-.25	-.52*	-.12	-.27	-.34	.13	1.00				
LTra	-.22	.25	.44	.19	.22	.42	-.20	-.31	1.00			
DSp	-.16	.45	.33	.19	.33	.42	-.30	-.24	.46	1.00		
LMem	-.13	.38	.51*	.19	.32	.39	-.20	-.50*	.44	.40	1.00	
VisR	-.23	.40	.33	.28	.25	.30	-.20	-.11	.31	.30	.28	1.00

TABLE 22 : Intercorrelations between 11 tests (12 measures) of the perceptual-cognitive battery for 105 subjects. TT:Token Test, PArr:Picture Arrangement, PCom:Picture Completion, LCEr:Letter Cancellation Errors, LCT:Letter Cancellation Time, RMT:Road Map Test, PCop:Pattern Copying, EFT:Embedded Figures Test, LTra:Line Tracing, DSp:Digit Span, LMem:Logical Memory, VisR:Visual Reproduction

from the 11 test items (2 measures for the Letter Cancellation Test - Error Score and Time). As can be seen from Table 22, seven of the coefficients of correlation for the raw scores demonstrated some overlap between the tests ($r>.5$).

Of particular interest were the positive associations between the Picture Arrangement and the Picture Completion Tests ($r=.56$); the Picture Arrangement and Road Map Tests ($r=.55$); Letter Cancellation Time and the Road Map Test ($r=.53$); the Picture Completion and Logical Memory Tests ($r=.51$) and the Picture Completion and the Road Map Tests ($r=.56$). There were two significant correlations difficult to interpret. The Embedded Figures Test was negatively correlated with the Picture Completion (-.52) and Logical Memory (-.50) Tests. This may, in the case of the EFT and the Logical Memory Test, indicate that those with sound auditory skills have less efficient visual-perceptual systems (and vice-versa). As both the EFT and Picture Completion Test involve figure-ground discrimination skills, this negative association is more difficult to explain.

As the analysis showed that only 25% of the common variance was accounted for, none of these tests overlap enough to make any redundant. In order to investigate these intercorrelations further, a principal components analysis was performed, followed by varimax rotation.

Initially, on the basis of clinical experience and the results of other studies on driving, it was predicted that the 11 tests in the battery would be grouped into three factors. However, statistical analysis provided support for two factors only, accounting for 48.6% of the variance (Table 23). It was of particular interest that the two factors which emerged were Visual-Perceptual Motor skills and Memory, but the third predicted component of General Intellectual Functioning was not indicated. The tests initially chosen to be a general measure of intelligence were Picture Arrangement and the Token Test. Picture Arrangement, as a non-verbal measure of reasoning ability, involving the manipulation and spatial arrangement of cards to tell a story, loaded heavily on Factor 1. Conversely, the Token Test, assessing the ability to understand and follow verbal instructions loaded on Factor 2. These two tests cannot therefore be considered to form a third component within this perceptual-cognitive battery.

As shown in Table 23, Factor 1, accounting for 37.8% of the variance loaded most highly on Picture Arrangement, Line Tracing, Letter Cancellation Time, Pattern Copying, Visual Reproduction and the Embedded Figures Test. As these tests seem to be primarily dependent on a combination of purely visual-perceptual skills and visual-motor coordination,

TEST	FACTOR 1	FACTOR 2
PICTURE ARRANGEMENT	.77	
LINE TRACING	.77	
LETTER CANCELLATION TIME	-.76	
PATTERN COPYING	.61	
VISUAL REPRODUCTION	.56	.53
EMBEDDED FIGURES	.52	
DIGIT SPAN		.65
LETTER CANCELLATION SCORE		-.63
TOKEN TEST		-.62
LOGICAL MEMORY		.55
PICTURE COMPLETION	.51	.52
ROAD MAP TEST		.50

TABLE 23 : Factor loadings from varimax rotated principal components analysis of test scores for 108 subjects. (Loadings less than .50 excluded.)

the Factor was therefore called Visual-Perceptual Motor Skill.

Factor 2 loaded most highly on Digit Span, Letter Cancellation Error Score, Token Test, Logical Memory, Picture Completion and the Road Map Test, accounting for an additional 10.8% of the variance. These tests seem to require the use of attentional mechanisms and the retention of new information (Digit Span, Letter Cancellation Error

Score, Token Test and Logical Memory) or past experience and learning (Picture Completion, Road Map Test). Factor 2 was therefore named Attention and Memory.

It should also be noted that Visual Reproduction, which involved memory for, and drawing of shapes, loaded equally on both Factor 1 and Factor 2. This was also true of the Picture Completion Test, which relied on good visual discrimination skills, in addition to past experience for successful completion.

It will be remembered, that the 19 subjects in the able-bodied group demonstrated significantly superior performance on all tests on Factor 1, confirming this Factor of Visual-Perceptual Motor Skill as an important component of the test battery and a major discriminator between those with and without a physical handicap.

2. THE PREDICTION OF DRIVING SUCCESS

The results of the analyses described above have demonstrated that the 11 tests in the perceptual-cognitive battery fall into two groups, each of which seem to have some face validity in relation to the task of driving. We can now turn to the question of primary interest in this thesis ie. whether scores on the tests in the battery can be used to predict driving potential in nondrivers with spina bifida and hydrocephalus. To do this, we need to consider test scores against final driving outcome. The outcome measure chosen to judge success in learning to drive was passing the Department of Transport Driving Test.

2.1. DESCRIPTION OF THE SAMPLE

Two of the 73 young people with spina bifida and hydrocephalus, described in the previous chapter, were still having tuition and were therefore excluded from this part of the analysis. The remaining 71 Ss were divided into two groups:- (i) those who had passed the Driving Test (40 Ss) and (ii) those who had not started tuition following assessment or who had failed a test and were no longer having driving lessons (31 Ss).

2.2. STATISTICAL ANALYSES

Two statistical procedures were employed to examine the relationship between performance on the test battery and success in driving. Firstly, two sets of One Way Analyses of Variance were performed to make comparisions between the scores of drivers and nondrivers on each test. The first set of analyses considered the scores of the 71 Ss on the 8 tests of the original battery, whilst the second set compared drivers and nondrivers who had completed the 11 tests of the amended battery.

statistical analysis used was Canonical Discriminant Function Analysis. This seemed a more appropriate method of analysis than a Multivariate Analysis of Variance as, at this stage, only two groups were to be considered - drivers and nondrivers. The purpose of using this method was to determine whether a combination of tests might provide a more accurate prediction of driving success than one specific test.

2.3. THE RESULTS

2.3.1. ANALYSES OF VARIANCE : One Way Analysis of Variance of the scores of 40 drivers and 31 nondrivers on the original 8 tests demonstrated that the only significant difference between scores was on the Picture Completion Test ($p<.05$) (Table 24). The drivers in this group showed finer discrimination based on the ability to note the missing part of an object or simple scene. There was no indication that the drivers demonstrated a higher level of reasoning ability, finer motor co-ordination or significantly better retention than nondrivers. However, as the nondrivers formed a diverse group, including those who had started tuition but never passed or taken a test, as well as those who had never attempted to learn to drive. The scores of the drivers were therefore compared to two subgroups of nondrivers - 8 Ss who had started tuition, but had given up before taking a Driving Test; and 22 Ss who

TEST*	DRIVERS n=40	NONDRIVERS n=31	F	p
TOKEN TEST	.60	.68	.07	ns
PICTURE ARRANGEMENT	15.38	15.71	.06	ns
PICTURE COMPLETION	10.60	9.03	3.95	.05
LETTER CANCELLATION				
(a) no. of errors	1.60	1.39	.13	ns
(b) time in secs.	139.83	141.35	.04	ns
ROAD MAP TEST	13.13	13.42	.20	ns
DIGIT SPAN TEST	10.03	10.23	.15	ns
LOGICAL MEMORY TEST	7.03	6.10	1.23	ns
VISUAL REPRODUCTION	6.28	6.35	.01	ns

TABLE 24 : Analyses of Variance between scores of drivers and nondrivers on 8 tests * High scores indicate good performance except for Token and Letter Cancellation Tests.

had never started tuition. (The S who had taken and failed a test was omitted as a special case.)

The results of the Analyses of Variance for these three groups are shown in Table 25. Once again, the only significant difference between test scores was on the Picture Completion Test. However, of particular interest was the finding that on this and all other tests, the scores of those who had not yet attempted to drive were

TEST*	DRIVERS	NOT STARTED DRIVING	STOPPED TUITION	F	p
	n=40	n=22	n=8		
TOKEN TEST	.60	.69	.75	.06	ns
PICTURE ARRANGEMENT	15.38	17.05	12.25	2.13	ns
PICTURE COMPLETION	10.60	9.68	7.63	3.03	.05
LETTER CANCELLATION					
(a) no. of errors	1.60	1.09	2.13	.54	ns
(b) time in secs.	139.83	141.41	136.25	.09	ns
ROAD MAP TEST	13.13	13.82	12.00	1.48	ns
DIGIT SPAN TEST	10.03	10.36	10.50	.38	ns
LOGICAL MEMORY TEST	7.03	6.64	5.50	.93	ns
VISUAL REPRODUCTION	6.28	7.09	4.63	2.16	ns

TABLE 25 : Analyses of Variance between scores of drivers, those who have not yet started tuition and those who have discontinued tuition on 8 tests

*High scores indicate good performance except for Token and Letter Cancellation Tests.

closer to the scores of the drivers rather than those who had given up tuition. In fact, on four tests (Picture Arrangement, Letter Cancellation Error, Road Map Test and Visual Reproduction) those who had not started tuition performed better than the drivers. Moreover, the fact that those who had given up tuition scored poorly on all but two tests (Letter Cancellation Time and Digit Span) may indicate that these were the "failures" rather than those who had not yet had the opportunity to learn to drive.

Within the group of 71 Ss, 23 drivers and 16 nondrivers had also completed the three additional tests (Pattern Copying, Line Tracing and Embedded Figures Tests). As Table 26 shows, comparison of the scores of the drivers, those who had not yet started tuition and those who had stopped tuition, followed a similar pattern to scores for the first eight tests. (The high mean score on the Pattern Copying Test for those who had not yet started tuition was due to four Ss who scored 11-16 points). Considering the three tests together, the Picture Completion, Line Tracing and EFT all rely on the ability to extract the essential elements from a visual display for successful completion. This fits in well with the results of the studies reported in Chapter Two, which emphasised the importance of sound perceptual-cognitive skills for safe driving.

These findings have important implications for further analyses which consider driver and "nondriver" groups. However to maintain adequate numbers of Ss in the groups to be considered, further analyses were made on two rather than three groups.

2.3.2. DISCRIMINANT FUNCTION ANALYSES : In order to further explore the relationship between perceptual-cognitive test scores and driving success, Discriminant Function Analysis

(DFA) was used. In the first analysis, the scores of 71 Ss on 8 test scores produced only one discriminant function (Table 27). It can be seen from Table 27, that high scores on the Picture Completion and Logical Memory Tests

TEST	DRIVERS	NOT STARTED TUITION	STOPPED TUITION
	n=23	n=11	n=5
PATTERN COPYING	5.26	7.18	2.00
LINE TRACING	4.57	3.82	3.40
EMBEDDED FIGURES	4.87	4.45	2.80

TABLE 26 : Scores of drivers and nondrivers on Pattern Copying, Line Tracing and Embedded Figures Test.

were necessary for a person to achieve a discriminant score in the driver range. However, the formula from the combination of weighted scores only correctly classified 62% of Ss into driver or nondriver groups.

To further assess the contribution of the three additional tests (Pattern Copying, Line Tracing and the Embedded Figures Tests) to the prediction of driving potential, a second DFA was performed on the scores of the 39 subjects who completed the battery of 11 tests. Again, only one function was produced, but with an increased predictive accuracy of 71.8%. Scores on the Line Tracing and Embedded

TEST	STANDARDISED DISCRIMINANT FUNCTION COEFFICIENT
PICTURE COMPLETION TEST	.64
LOGICAL MEMORY TEST	.36
ROAD MAP TEST	-.15
DIGIT SPAN TEST	-.12
LETTER CANCELLATION (errors)	.12
TOKEN TEST	-.08
PICTURE ARRANGEMENT TEST	-.08
LETTER CANCELLATION (secs)	-.07
VISUAL REPRODUCTION TEST	-.04

TABLE 27 : Standard Discriminant Function Coefficients for 8 tests.

Figures Tests, together with the Token Test correlated most highly with the Discriminant Function (Table 28).

Interestingly, for this group of 39 Ss, the DF produced by analysis of 9 variables only, also correctly predicted 71.8% group membership. The tests which correlated most highly with the DF again included the Token, Picture Completion and Logical Memory Tests (Table 29).

As scores on the Picture Completion and Logical Memory Tests had contributed strongly to the DF in both sets of analyses, a further DFA was performed from the scores of these two tests, together with scores from the Line Tracing and EFT. The DF produced accurately predicted 69.2% of drivers and non-drivers in this group. It is significant to note again, that three of these tests, excluding Logical Memory, depended on figure-ground discrimination skills for successful completion. The addition of the Token Test to

TEST	STANDARDISED DISCRIMINANT FUNCTION CO-EFFICIENT
LINE TRACING TEST	-.48
EMBEDDED FIGURES TEST	-.45
TOKEN TEST	.44
PICTURE COMPLETION TEST	-.37
LOGICAL MEMORY TEST	-.20
LETTER CANCELLATION(secs)	.19
DIGIT SPAN TEST	.17
LETTER CANCELLATION(errors)	.13
VISUAL REPRODUCTION TEST	-.11
ROAD MAP TEST	-.04
PICTURE ARRANGEMENT TEST	.02
PATTERN COPYING TEST	.00

TABLE 28 : Standard Discriminant Function coefficients for 11 tests.

successful completion. The addition of the Token Test to the analysis increased the predictive accuracy of the equation to 74.4%.

It is significant to note that the classifications based on the DF equations from the test scores of the 39 Ss, made a higher percentage of inaccurate predictions for those, who, on the basis of test results, should have become drivers, but did not (false positives). As Table 30 shows, 31-38%

TEST	STANDARDISED DISCRIMINANT FUNCTION COEFFICIENT
TOKEN TEST	.59
PICTURE COMPLETION TEST	-.49
LOGICAL MEMORY TEST	-.27
LETTER CANCELLATION(secs)	.26
DIGIT SPAN TEST	.23
LETTER CANCELLATION(errors)	.18
VISUAL REPRODUCTION TEST	-.14
ROAD MAP TEST	-.05
PICTURE ARRANGEMENT TEST	.03

TABLE 29 : Standard Discriminant Function Coefficients for 8 tests for 39 subjects.

of nondrivers were incorrectly classified in this way, compared with 21-27% of drivers being misclassified as nondrivers. This may suggest that other variables may need to be carefully assessed, in addition to cognitive skills.

GROUP	PREDICTED GROUP MEMBERSHIP	
	DRIVER	NONDRIVER
1. 4 MEASURES		
DRIVER	17 (73.9%)	6 (26.1%)
NONDRIVER	6 (37.5%)	10 (62.5%)
2. 9 MEASURES		
DRIVER	18 (78.3%)	5 (21.7%)
NONDRIVER	6 (37.5%)	10 (62.5%)
3. 12 MEASURES		
DRIVER	17 (73.7%)	6 (26.1%)
NONDRIVER	5 (31.3%)	11 (68.8%)

TABLE 30 : Predicted group membership of 23 drivers and 16 nondrivers showing percentage misclassification based on three Discriminant Function equations.

3. DISCUSSION

As discussed in the introduction to Chapter Seven, the items for the perceptual-cognitive battery used in this thesis, were chosen partly on the basis of the little information concerning driving available at the beginning of the 1980s, partly on the SB literature and partly on clinical intuition. Since that time and in parallel with this study, interest in cognitive deficit and driving has increased dramatically. The results of studies from assessment centres and research institutions throughout the world began to reveal that the association between the results of clinical cognitive tests and the driving behaviour of those returning to driving following brain damage was not as close as had been hoped. The results of the study presented in this thesis, concerning young SBH adults with no driving experience, unfortunately, so far, seemed to confirm the findings that scores on cognitive tests alone cannot reliably predict success in reaching Driving Test standard.

However, an interesting finding was the differences in test scores between those who had become drivers and those who had "failed" during the tuition period, although had never taken a test. This latter group, although small did seem to score poorly on many tests, whilst those who had not yet started tuition, in general, demonstrated cognitive abilities in the same range as the drivers. In view of these findings, there seemed to be two ways to proceed. Firstly we could consider the possible contribution to driving success of factors other than cognitive variables. This was highlighted in the previous section when it was noted that a higher percentage of misclassifications (based on Discriminant Function equations) were for nondrivers who performed well on the perceptual-cognitive battery but who did not become drivers. Over the period of this study, my own work at Banstead Mobility Centre has also clearly shown that even with adequate cognitive skills on driving assessment and motivation to learn, whether a person begins tuition depends on financial and practical resources. In particular, the availability of knowledgeable local driving instructors is important for all learner drivers. Thus, if this approach were to be pursued, a broader based assessment procedure might be better.

Bearing the results of this and other studies in mind, together with the points mentioned above, it became obvious over the course of this work that the prediction of driving success by perceptual-cognitive test scores was an ambitious, if not impossible task. This rather negative view was balanced by the fact that the results from the studies reported here are at least sufficiently encouraging to consider a second approach. This would be to examine the prediction of driving success in a more controlled and measurable way, reducing extraneous variables which might affect learning in real life during the tuition period.

The following chapter, therefore, presents the results of a subsequent more compact study, which considered in detail a small group of 14 young learner drivers with spina bifida and hydrocephalus. Of particular importance was the consideration of whether a structured tuition programme could help some of those with spina bifida and hydrocephalus to compensate for learning difficulties.

CHAPTER NINE : STRUCTURED TUITION FOR LEARNER DRIVERS

So far, this thesis has dealt with a broad evaluation of cognitive assessment for driving. The results have indicated that the particular battery of clinical measures, chosen to assess cognitive functioning, did not predict driving success (as assessed by passing the Department of Transport Driving Test) accurately enough for it to be worth pursuing the line of research in exactly the same way. However, from the results obtained, there was sufficient reason to believe that it was worth continuing in a slightly different way. As mentioned above, there were often clearly identifiable reasons for learners not reaching Driving Test standard. However, these were not entirely predictable and were totally unrelated to an individual's performance on the test battery. One major decision that was made, therefore, was to pursue the question of the predictive validity of the battery in a much more narrowly defined context. Another general strategy decision that was made concerned the expansion of the battery itself and the use of new evaluative measures.

Before continuing in detail, the general strategy decisions mentioned above need elaboration.

CONTROL OF EXTRANEOUS VARIABLES : The drivers and learner drivers considered in Chapters Seven and Eight had arranged tuition in their home areas with local instructors. It is therefore likely they will have been taught by different methods with varying lesson frequency. As these variables may have made a significant contribution to the quality of tuition and eventual success in reaching Driving Test standard, a study which partialled out differences during tuition would allow a purer assessment of the effects of cognitive variables on learning. By careful structuring of tuition, therefore, extraneous variables relating to instructor techniques could be eliminated. Similarly, the provision of suitably adapted cars would ensure that pupils were not hampered by trying to master inappropriate car controls.

ASSESSMENT MEASURES : As the perceptual-cognitive tests chosen had not proved sufficiently reliable predictors of driving success, it was necessary to consider the use of other objective measures. Inclusion of additional clinical tests of cognitive function was rejected in favour of practical tests assessing "real-life" skills, to ensure at least some face validity for driving. As will be described, the three tests eventually chosen for the focussed study were considered to assess spatial and directional orientation by the use of maps and visual disembedding using photographs of street scenes.

The opportunity to undertake a well controlled study incorporating the ideas and developments just described arose at a suitable moment. The Association for Spina Bifida and Hydrocephalus (ASBAH) was in the process of organising residential driving courses for small groups of "would-be" drivers. I was able to participate in the planning of these courses, thus incorporating my own assessment measures and structured tuition plan as a fundamantal part of the programme (Appendix V). In the following sections the study will be outlined in two parts, each related to three main aims:-

(i) To develop new assessment procedures for the evaluation of both pre-driving skills and progress during the early tuition period.

(ii) To further investigate whether perceptual-cognitive and/or practical pre-driving tests can predict driving performance on off-road driving tasks.

(iii) To assess whether performance during the early tuition period can predict later success in passing the Driving Test.

1. PART I : PRE-DRIVING ASSESSMENTS

The objective of this part of the study was to examine all of the assessment instruments, old and new, on the Ss taking part in the new phase of the study.

1.1. DESCRIPTION OF SAMPLE

A total of 14 learner drivers attended the driving courses, which were based at Five Oaks Activity Centre, Ilkley, West Yorkshire, a residential ASBAH centre. Three residential courses, each of two weeks duration, were held over a one year period.

As described in Table 31, 9 males and 5 females with spina bifida myelomeningocele and shunt-treated hydrocephalus took part in a driving course. The mean age of the males was 18 years 4 months (range: 16-25 years) and of the females 20 years 6 months (range: 17-27 years). Although, none demonstrated medical or visual disabilities representing a "bar" to driving, all except two had visual deficits. Two males and two females were walkers, the remaining ten being totally wheelchairbound. All were considered physically able to control a suitably adapted car, using hand controls.

SUBJECT NO.	SEX M/F	AGE YRS	MOBILITY	VISUAL DEFECT* SQUINT	NYSTAGMUS	DISTANCE GLASSES	FIELD DEFECT
1	M	19	WHEELCHAIR	X	X		
2	F	17	WALKER				
3	M	23	WHEELCHAIR	X		X	X
4	F	17	WALKER				X
5	F	20	WHEELCHAIR	X	X	X	
6	M	21	WHEELCHAIR	X			X
7	M	17	WALKER	X		X	
8	M	20	WHEELCHAIR	X		X	X
9	M	25	WHEELCHAIR	X		X	X
10	M	19	WHEELCHAIR				X
11	M	16	WALKER				
12	M	16	WHEELCHAIR	X		X	X
13	F	27	WHEELCHAIR	X		X	
14	F	19	WHEELCHAIR	X			X

TABLE 31 : Details of the 14 young people with SBH who attended a driving course. *No defect was a bar to driving.

1.2. NEW DEVELOPMENTS IN THE ASSESSMENT PROCEDURES

In addition to the 11 perceptual-cognitive tests, described in the two previous chapters, three new tests were introduced to the battery. These new tests were designed to assess spatial and directional orientation and visual disembedding in a situation more closely akin to the driving task ie. in practical, but non-driving situations. The three tests chosen were (a) an adapted version of Weinstein's Extrapersonal Orientation Test (Weinstein et al, 1956), and two tests specially designed for this study (b) the Route Finding Test and (c) the Embedded Traffic Signs Test. A description of each test, together with details of presentation and scoring, is given below.

EXTRAPERSONAL ORIENTATION TEST (Weinstein et al, 1956)

This test was adaptated from a technique devised by Weinstein et al (1956) as an objective measure of spatial orientation. The test measures the ability to understand the connections between points on a map and to demonstrate that knowledge by following the route shown. This test has not been used in previously reported driving studies, but Semmes et al (1963) have reported that Ss with brain damage (in particular parietal lobe damage) are often impaired on this task.

TEST PRESENTATION

The task was to follow "maps" drawn on a dot matrix on a card, on an analagous matrix drawn on the ground. Ss either walked the route or pushed themselves in their wheelchairs. In this study, five visual maps were drawn on a 9 dot matrix 6 cms. square (Figure 14). A 9 dot matrix 2.5ms. square was marked on the ground. Instructions

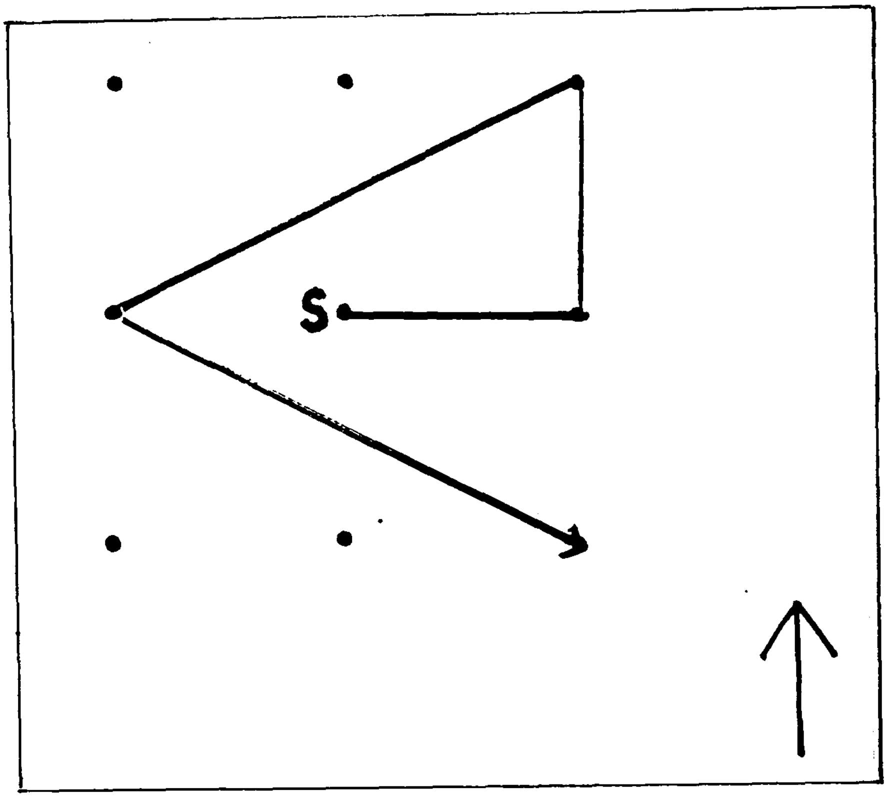


FIGURE 14 : Example of a visual map from the Extrapersonal Orientation Test (Weinstein et al, 1956).

were given as follows - "Please follow the path shown on this map (show Practice Card 1), on the dots marked here on the ground". Two practice trials were followed by five trials with paths of increasing length.

TEST SCORING

The number of correct turns was scored for each map. Maximum score : 44.

ROUTE FINDING TEST

This test was designed for this study to assess an individual's ability to derive information from a map and to use the information to give directions. It is an extension of the Extrapersonal Orientation Test, described above, in that it also requires verbalisation and the ability to understand the relationship between features shown on a map. The task was to direct the driver along a route marked on a large scale, street map. This involved giving directions for 20 left and right turns.

TEST PRESENTATION

Each subject was taken individually as a passenger over a set route of 4 miles. At the beginning of the drive, the S was shown the route map with the following instructions - "We are here (Indicating on the map). This route marked here shows the way we want to go. Please give the driver the directions to follow this route, telling her when to turn left or right." An observer sat in the back of the car to score directions and to redirect the driver if necessary.

TEST SCORING

Each correct direction given for the 20 turns was scored 1. Maximum score : 20.

EMBEDDED TRAFFIC SIGNS TEST

This test was also designed specifically for this study to measure verbal response times to traffic signs embedded in photographs of street scenes. Shoptaugh and Whitaker (1984) used a similar task, with tachistoscopic presentation of street scenes of varying background complexity, to investigate differences in response times between those assessed as field dependent/independent. This task has not previously been used to assess drivers with known brain damage.

TEST PRESENTATION

The stimuli were 6 mounted traffic signs (4.5cm. x 4.5cm.) and 10 coloured photographs (13 cm. x 9 cm.) of street scenes (Figure 15). Ss were shown a traffic sign and a photograph, with the following instructions - "Please find this sign in this photograph as quickly as you can". Two practice trials were given.

TEST SCORING

Response times were recorded for the 10 items.

1.3. PROCEDURE

Prior to the courses all learner drivers had been assessed for driving at Banstead Mobility Centre. This included completion of the 11 tests of the perceptual-cognitive battery. At the beginning of each course, the three

FIGURE 15 : Example of a photograph of a road scene from the Embedded Traffic Signs Test.

additional practical tests - Extrapersonal Orientation, Route Finding and Embedded Traffic Signs Tests - were also presented as described in the previous section.

1.4. RESULTS

Scores on the 11 perceptual-cognitive tests are considered first. This is followed by presentation of the data relating to the three practical pre-driving measures - Extrapersonal Orientation Test (EOT), Embedded Traffic Signs Test (ETST) and the Route Finding Test (RFT).

1.4.1. PERCEPTUAL-COGNITIVE TEST SCORES : The mean scores on the 11 tests of the perceptual-cognitive battery, for this small group of 14 learner drivers, were similar to those of the group of 39 subjects, discussed in the previous chapter. As Table 32 shows, scores obtained were generally well below the maximum possible scores (although the range of scores was characteristically wide). For the Wechsler tests for which norms were applicable (Picture Completion, Digit Span, Logical Memory and Visual Reproduction Tests), except for the Digit Span Test, mean scores were below average.

However, unlike in earlier analyses, there seemed to be a marked difference in performance on the battery between the males and the females (Table 33). The males were significantly better on four of the eleven tests (Picture Arrangement, Road Map, Digit Span and Logical Memory Tests) and on five more the difference was also in that direction. The 5 females in this group demonstrated limited cognitive abilities for tests of both memory and visual-perceptual motor functioning.

1.4.2. PRACTICAL PRE-DRIVING MEASURES : As these tests were new, qualitative observations of performance on the Extrapersonal Orientation, Route Finding and Embedded Traffic Signs Tests accompany statistical analysis for each test.

TEST*	MEAN	SD	RANGE
TOKEN TEST	.50	.65	0-2
PICTURE ARRANGEMENT	14.29	6.46	4-26
PICTURE COMPLETION	10.64	4.33	5-18
LETTER CANCELLATION			
(a) no. of errors	1.21	1.19	0-4
(b) time in secs	158.43	47.08	104-280
ROAD MAP TEST	12.57	4.38	2-16
PATTERN COPYING	5.36	4.72	0-16
EMBEDDED FIGURES	4.86	1.61	2-6
LINE TRACING	3.50	1.51	1-7
DIGIT SPAN	10.21	2.58	7-15
LOGICAL MEMORY	4.93	3.34	0-11
VISUAL REPRODUCTION	6.00	2.75	2-9

TABLE 32 : Means, standard deviations and range of scores for 14 SBH learner drivers on the perceptual-cognitive battery. *High scores indicate good performance except for scores on the Token and Letter Cancellation Tests.

EXTRAPERSONAL ORIENTATION TEST : Many learners found this test difficult. Whilst following the route, they needed constant reminders to adjust their own position and the matrix on the card, in relation to the matrix drawn on the ground. Of a possible score of 44, males obtained a mean score of 33.1 correct turns compared with the females 23.4

TEST*	MALES n=9	FEMALES n=5	F	p
TOKEN TEST	.56	.40	.17	ns
PICTURE ARRANGEMENT	17.11	9.20	7.07	.05
PICTURE COMPLETION	11.89	8.40	2.30	ns
LETTER CANCELLATION				
(a) no. of errors	1.33	1.00	.24	ns
(b) time in secs	162.44	151.20	.17	ns
ROAD MAP TEST	14.22	9.60	4.56	.05
PATTERN COPYING	7.00	2.40	3.69	.08
EMBEDDED FIGURES	5.22	4.20	1.33	ns
LINE TRACING TEST	3.67	3.20	.29	ns
DIGIT SPAN TEST	11.33	8.20	6.91	.02
LOGICAL MEMORY TEST	6.67	1.80	13.28	.003
VISUAL REPRODUCTION	6.89	4.40	3.06	ns

TABLE 33 : Means on 11 perceptual-cognitive tests for males and females in SBH learner driver group. * High scores indicate good performance except for scores on Token and Letter Cancellation Tests.

correct turns. Differences were significant at the .007 level.

ROUTE FINDING TEST : This task also proved difficult for many learners, particularly the females. The females achieved a mean score of 11, from a possible maximum of 20, compared with the males' mean score of 17. Differences were significant at the .01 level.

EMBEDDED TRAFFIC SIGNS TEST: There was a wide variation both within and between Ss in the time taken to find the traffic signs embedded in the street scenes. There was again a sex difference, this time in favour of females, who were on average more than twice as fast as the males. The mean score for the males was 14.5 seconds compared with the females at 6.5 seconds ($p < .06$). This test also seemed sensitive to the presence of visual defects, those with squints or visual field loss taking twice as long to note the traffic signs. This may partly account for the better performance of the females, a smaller percentage of whom demonstrated visual defects, as shown in Table 31.

This wide distribution of scores achieved by this small group of 14 learner drivers indicates that both the perceptual-cognitive battery and the three newly introduced practical tests discriminate quite well between the different levels of ability within the group.

2. PART II : THE PREDICTIVE VALIDITY OF THE TESTS

Having demonstrated the usefulness of the new tests, we now turn to the main issue - can driving ability be predicted? An attempt is made to answer two specific questions:- (a) can pre-driving measures predict performance on off-road manoeuvres? and (b) can performance during early tuition predict later Driving Test success? The first question can be answered by consideration of the results of the scores on the pre- and post-tuition measures used during the driving courses. The post-tuition measures comprised off-road manoeuvres and a Driving Checklist, both being described below. To answer the second question, the learner drivers needed to be contacted several years after the course for information on driving status.

2.1. THE SAMPLE

The Ss were those already described on page 218.

2.2. DEVELOPMENT OF THE IN-CAR ASSESSMENT

Two approaches were taken to the assessment of progress during the early tuition period. Firstly, objective measurements were made on in-car performance during off-road manoeuvres designed to assess car control skills. Secondly, the driving instructor was asked to rate each learner's in-car competence and suitability for further tuition, as demonstrated during the first ten hours tuition.

2.2.1. OFF-ROAD MANOEUVRES

Off-road manoeuvres involved two tasks, Straight Tracking and Figure of 8, taken almost directly from the work of Sivak et al (1981) quoted earlier.

STRAIGHT TRACKING (Sivak et al, 1981) : This off-road test was used by Sivak et al (1981) to assess the car control skills of brain-damaged drivers. In the test, two parallel lines of 20 cones each were positioned to form a road 55 metres in length and 60 cms greater than the width of the car being used. The task was to drive quickly through the lines without touching any cones.

TEST PRESENTATION

The instructions were - "Drive between the two lines of cones as fast as you can without touching them". Three trials were given.

TEST SCORING

The time for each trial and number of cones displaced was recorded.

FIGURE OF 8 (Sivak et al, 1981) : This off-road test was also used by Sivak et al (1981). Two cones were placed 18 metres apart, the task being to drive in a Figure of 8 around the cones.

TEST PRESENTATION

The instructions were given as follows - "Drive in a Figure of 8 pattern around the 2 cones ahead of you as fast as you can". A diagram of the manoeuvre was used to supplement verbal instructions. Three trials were given.

TEST SCORING

The time for each trial was recorded.

2.2.2. DRIVING CHECKLIST

At the end of the 10 hour tuition period, driving instructors completed a checklist for the pupils they had taught. This Checklist had originally been developed for use with learner drivers at Banstead Mobility Centre and had been found to have good inter-rater reliability. As Table 34 shows, pupils were rated on nine aspects of on-road driving performance and suitability for further tuition. Rating was on a five point scale. A global on-road driving score was achieved by a summation of the ratings. Maximum score : 50.

2.3. PROCEDURE

On the ten weekdays of the course, each learner driver received one hours in-car tuition, supplemented by classroom work related to driving. Although, during the classroom sessions, much valuable information was gained on the learning strategies of this SBH group, this thesis

	HIGH				LOW
1. <u>PREDRIVING CHECK</u>	5	4	3	2	1
2. <u>USE OF CAR CONTROLS</u>	5	4	3	2	1
3. <u>STEERING CONTROL</u>	5	4	3	2	1
4. <u>USE OF MIRRORS</u>	5	4	3	2	1
5. <u>SIGNALLING</u>	5	4	3	2	1
6. <u>AWARENESS OF TRAFFIC LIGHTS AND SIGNS</u>	5	4	3	2	1
7. <u>AWARENESS OF OTHER ROAD USERS</u>	5	4	3	2	1
8. <u>ROAD POSITIONING</u>	5	4	3	2	1
9. <u>SPEED</u>	5	4	3	2	1
10. <u>SUITABILITY FOR FURTHER TUITION</u>	5	4	3	2	1

TABLE 34 : Driving Checklist

focusses primarily on the outcome of the in-car tuition.

Learners had tuition on one of three cars - an automatic Mini, Cortina or Maestro, all suitably adapted with hand controls and seating modifications where necessary. The first four hours tuition took place on the off-road tracks of a local Driver Training Centre. The following six hours tuition were conducted on public roads in the Ilkley area.

On the last day of the course, the off-road manoeuvres were completed on the driver training track used for the early tuition period. A driving instructor sat in the car during these tests, but was asked only to intervene in an emergency situation. At this stage, the driving instructors also completed the Driving Checklist on the pupils they had taught.

2.4. RESULTS

2.4.1. CAN PERCEPTUAL-COGNITIVE TESTS OR PRACTICAL PRE-DRIVING TESTS PREDICT OFF-ROAD DRIVING PERFORMANCE?

OFF-ROAD DRIVING PERFORMANCE : Mean scores for the off-road driving tests are given in Table 35. As noted with other tests, the range of ability displayed during the off-road manoeuvres was wide. Fifty percent of the group completed the Straight Tracking Test without displacing cones, achieving a mean time of 12.7 seconds. This was slightly

TEST	MEAN	SD	RANGE
STRAIGHT TRACKING			
(a) time in secs	12.16	4.26	7-23
(b) cones displaced	1.57	1.99	0-5
FIGURE OF 8 (time)	22.46	5.87	13-35

TABLE 35 : Mean scores, standard deviations and range of scores for off-road driving manoeuvres for 14 SBH learner drivers.

longer than the 11.6 seconds taken by those who did displace cones, possibly suggesting a more cautious approach to the task. Alternatively, as those who displaced cones on the Tracking Test were also slower on the more complex Figure of 8 Test, this may have indicated poor spatial ability or car control skills.

Comparison of the performance of males and females for the car manoeuvres was made by Analyses of Variance. Results demonstrated that although the males were overall faster and displaced fewer cones than the females, these differences were not significant.

Pearson correlation coefficients were calculated to determine the intercorrelation between pre-driving tests and off-road driving performance measures.

As shown in Table 36, five tests from the perceptual-cognitive battery (Token, Picture Completion, Embedded Figures, Logical Memory and Visual Reproduction Tests) correlated significantly with both practical tests (EOT, ETST and RFT) and off-road manoeuvres. Four of these five tests (excluding Visual Reproduction) were highlighted in the previous chapters as involving skills which might be important for driving.

Logical Memory seemed to be of importance for three tests (EOT, RFT, Figure 8) which involved the understanding and retention of instructions whilst performing lengthy, practical tasks (following a route on a matrix, following a street map, driving a Figure 8). It was also noted that only the Token Test score, assessing the ability to follow simple instructions, correlated with the Straight Tracking Test. In contrast, the more complex Figure of 8 manoeuvre was closely linked with visual-perceptual test scores and the ability to remember detailed verbal information.

Interestingly there was also a small group of correlations which appeared to measure a practically based spatial ability. These correlations were between the Road Map Test and the Extrapersonal Orientation Test; the Road Map Test and the Route Finding Test; the Visual Reproduction Test and the EOT; the Visual Reproduction Test and the Figure of 8 manoeuvre; the EOT and the Route Finding Test;

PERCEPTUAL-COGNITIVE	PRACTICAL TESTS			IN-CAR TESTS**	
TESTS	EOT	RFT	ETST	STR	FIG8
TOKEN TEST			.56	.51	
PICTURE ARRANGEMENT	.54	.46			
PICTURE COMPLETION	.53	.50			.50
LETTER CANCELLATION					
(a) no. of errors					.45
(b) time in secs					
ROAD MAP TEST	.68*	.54			
PATTERN COPYING	.52				
EMBEDDED FIGURES	.65*				.48
LINE TRACING		.45			
DIGIT SPAN TEST		.54			
LOGICAL MEMORY TEST	.79*	.65*			.63*
VISUAL REPRODUCTION	.74*				.69*
PRACTICAL NON-DRIVING TESTS					
EXTRAPERSONAL ORIENTATION TEST (EOT)		.75*			.71*
ROUTE FINDING TEST (RFT)					
EMBEDDED TRAFFIC SIGNS TEST (ETST)					

TABLE 36 : Intercorrelations ($p<.05$) between pre-driving measures and driving performance tests for 14 SBH learner drivers. * $p<.01$. **STR:Straight Tracking, FIG8:Figure of 8 Manoeuvre

the EOT and the Figure of 8. All five tests involved spatial organisation or spatial orientation and might, therefore, indicate potential ability to use maps or follow routes in those who became drivers. This interesting point cannot be fully discussed within the scope of this thesis, but will be mentioned in the later section concerning driving related learning.

2.4.2. CAN PERFORMANCE DURING EARLY TUITION PREDICT DRIVING TEST SUCCESS?

In December 1988, all those who had attended a driving course were contacted to ascertain whether they were drivers or nondrivers. Six had passed a Department of Transport Driving Test and five had had lessons but had never taken a Driving Test (3 had discontinued tuition, 1 was still having lessons and 1 had died). The remaining 3 learners had been discouraged by their limited progress during the course and had decided to have no further lessons.

To evaluate the predictive validity of scores on individual pre- and post-driving measures for Driving Test success, a series of One Way Analyses of Variance was first performed on the scores of the driver and nondriver groups. In addition, to evaluate the predictive validity of groups of tests, rather than individual measures, a second analysis, using the predictive equation derived from the scores of the 39 Ss discussed in the previous chapter, considered the classification of the smaller group of 14 learner drivers into driver and nondriver groups. Finally, a Discriminant Function Analysis was performed on the test scores of the 14 Ss to further consider the predictive validity of the perceptual-cognitive tests for driving.

PRE-DRIVING TESTS

Analyses of Variance were performed on the scores of driver and nondriver groups for the 11 perceptual-cognitive tests and the three practical tests (EOT, RFT, ETST). These are discussed separately in the section which follows.

PERCEPTUAL-COGNITIVE TEST SCORES : As shown in Table 37, drivers achieved higher scores on 9 of the 11 tests, four differences being significant at the .05 level or above. These were the Picture Arrangement, Picture Completion, Pattern Copying and Logical Memory Tests. However, as will be discussed in a later section, the driver group was comprised entirely of males. This bias might partly account for the significant differences between scores of drivers and nondrivers. In the earlier section considering score differences according to sex, Table 33 showed that males scored significantly higher than females on the Picture Arrangement and Logical Memory Test (and somewhat higher on Picture Completion and Pattern Copying, although the 5%

TEST	DRIVERS(n=6)		NONDRIVERS(n=8)		P
	MEAN	SD	MEAN	SD	
TOKEN TEST	.8	.8	.3	.5	ns
PICTURE ARRANGEMENT	19.0	5.0	10.8	5.1	.01
PICTURE COMPLETION	13.2	4.7	8.8	3.1	.05
LETTER CANCELLATION					
(a) no. of errors	1.3	1.5	1.1	1.0	ns
(b) time in secs	157.0	66.7	159.5	30.5	ns
ROAD MAP TEST	13.5	2.4	11.9	5.5	ns
PATTERN COPYING	8.3	5.0	3.1	3.2	.03
EMBEDDED FIGURES	5.3	1.2	4.5	1.9	ns
LINE TRACING	4.2	1.5	3.0	1.4	ns
DIGIT SPAN TEST	10.8	2.6	9.8	2.7	ns
LOGICAL MEMORY TEST	7.5	2.7	3.0	2.3	.006
VISUAL REPRODUCTION	7.5	1.6	4.9	2.9	ns

TABLE 37 : Raw scores of driver and nondriver groups on perceptual-cognitive battery.

level of confidence was not reached).

PRACTICAL PRE-DRIVING TESTS : Considering the practically based EOT, RFT and ETST scores, Table 38 shows that those who became drivers were more competent on the EOT and RFT than those who did not. Again this could be attributed to a sex difference for this group, as this trend reflected the differences in performance of the males and females.

TEST	DRIVERS		NONDRIVERS		p
	mean	sd	mean	sd	
EOT	33.3	5.6	26.9	7.2	.09
ETST (secs)	18.1	8.4	6.9	2.3	.004
ROUTE FINDING	17.3	2.4	13.0	5.2	.08

TABLE 38 : Scores of drivers and nondrivers on practical pre-driving measures.

POST-TUITION TESTS

The scores of the drivers and nondrivers on both the off-road manoeuvres and the Driving Checklist are considered in this section. The first of these two measures assessed skill based learning only - that is, car control skills in a traffic free environment. In contrast, the second measure, the Driving Ckecklist, not only rated the learner driver's ability to control the car, but also evaluated rule based learning associated with simple road procedures. The contribution of these two aspects of driving tuition to passing the Driving Test is considered in the following section.

OFF-ROAD MANOEUVRES : Performance of the in-car manoeuvres surprisingly, were not significantly different for drivers and nondrivers, although, as shown in Table 39, the drivers did perform the manoeuvres more quickly and displaced fewer cones. (This again reflected the

TEST	DRIVERS		NONDRIVERS		p
	MEAN	SD	MEAN	SD	
STRAIGHT TRACKING					
(a) time in secs	11.0	4.0	13.1	4.5	ns
(b) cones displaced	.7	1.2	2.3	2.3	ns
FIGURE OF 8 (secs)	19.7	5.4	24.5	5.6	ns

TABLE 39 : Scores of drivers and nondrivers for off-road manoeuvres.

differences in performance between males and females already noted.)

DRIVING CHECKLIST : Mean scores on the Driving Checklist are given in Table 40. It can be seen that although males in the group achieved an overall higher score than the females, there was more individual variation in their performance. Analysis of Variance demonstrated that differences between the scores of males and females were not statistically significant. An important, and perhaps not unexpected finding was, that at the end of ten hours tuition, the difference between the mean driving instructor rating of 34.8 for drivers and 26.1 for nondrivers was significant at the .03 level.

GROUPS OF TESTS AS PREDICTORS

Two separate analyses were used to consider the predictive

GROUP	MEAN	SD	RANGE
MALES(n=9)	30.67	8.49	16-43
FEMALES(n=5)	28.40	6.11	24-34
BOTH	29.86	7.56	16-43

TABLE 40 : Mean scores, standard deviations and range of scores on Driving Checklist for 14 SBH learner drivers.

validity for reaching Driving Test standard of groups of tests rather than individual measures. Firstly, the predictive equations derived from the DFA on the scores of 39 Ss assessed for driving ability were used with the scores of the 14 learners who attended a driving course. Secondly a DFA was performed on the scores of the 14 SBH learners, to further assess which tests contributed most to the prediction of driving ability in this group.

USE OF PREDICTIVE EQUATIONS : The equations for assigning learners to driver and nondriver groups, based on the DFA described in Chapter 8, are shown in Table 41. These equations only successfully classified 62.3% of the group of 14 as drivers or nondrivers (Table 42). This allows considerable room for error if predictions for group membership were to be based on the results of perceptual-cognitive tests alone. Two learners who were classified as nondrivers did pass the Driving Test, albeit

DRIVERS:	1.409234	x	TOKEN TEST (error) score	+
	.559494	x	PICTURE COMPLETION TEST score	+
	.243324	x	LOGICAL MEMORY TEST score	+
	.714873	x	LINE TRACING TEST score	+
	1.024362	x	EMBEDDED FIGURES TEST score	-
	8.814782		(constant)	
NONDRIVERS:	1.916658	x	TOKEN TEST (error) score	+
	.483854	x	PICTURE COMPLETION TEST score	+
	.281671	x	LOGICAL MEMORY TEST score	+
	.481025	x	LINE TRACING TEST score	+
	.881954	x	EMBEDDED FIGURES TEST score	-
	7.041372		(constant)	

TABLE 41 : Predictive equations used to classify driver and nondriver groups.

after a lengthy period of tuition. A further three learners classified as drivers did not achieve Test standard. However, one of these died soon after beginning tuition and one had no further lessons after completing the driving course. A further learner started lessons many months after the course and was still a learner driver when contacted for follow-up.

DISCRIMINANT FUNCTION ANALYSES : In the first analysis the scores of the 14 Ss on the 11 perceptual-cognitive tests,

ACTUAL GROUP	NO.	PREDICTED GROUP MEMBERSHIP	
		DRIVERS	NONDRIVERS
DRIVERS	6	4 (66.7%)	2 (33.3%)
NONDRIVERS	8	3 (37.5%)	5 (62.5%)

TABLE 42 : Percentage of learners correctly classified as drivers or nondrivers.

produced one Discriminant Function. As shown in Table 43, the tests which correlated most highly with the DF were the Logical Memory and Picture Arrangement Tests. The formula from the combination of weighted scores correctly classified all Ss into driver and nondriver groups.

To evaluate the effect of reducing the number of tests contributing to the predictive equation, the 6 tests which correlated most highly with the DF in the analysis described, were considered as a separate subgroup. Encouragingly, when scores on these 6 tests only were used to form the predictive equations, classification into driver and nondriver groups remained 100% accurate. However, a further reduction of the number of tests to 4, by excluding the Visual Reproduction and Token Tests, also reduced the predictive accuracy of the group of tests to 85.7%.

TEST	STANDARDISED DISCRIMINANT FUNCTION CO-EFFICIENT
LOGICAL MEMORY TEST	.16
PICTURE ARRANGEMENT TEST	.15
PATTERN COPYING TEST	.12
PICTURE COMPLETION TEST	.10
VISUAL REPRODUCTION TEST	.10
TOKEN TEST	.09
LINE TRACING TEST	.07
EMBEDDED FIGURES TEST	.05
DIGIT SPAN TEST	.04
ROAD MAP TEST	.03
LETTER CANCELLATION (errors)	.02
LETTER CANCELLATION (secs)	-.00

TABLE 43 : Standard Discriminant Function coefficients for 11 tests for 14 SBH Ss.

2.5. SUMMARY

In summary therefore, there were indications from the test scores and off-road driving performance of this small group of 14 learner drivers, that the ability to follow verbal instructions (Token Test), remember new information (Logical Memory and Visual Reproduction Tests) and visually extract details from a complex background (Picture Completion and EFT) may be determinants of a learner driver's ability to perform off-road manoeuvres. This supports the findings of studies, mentioned in Chapter Three, concerning the limited correlation between clinical tests and on-road performance of persons with brain damage (Schweitzer et al, 1988; Van Zomeren et al, 1988).

With such small numbers, generalisations would not be valid, but, bearing this in mind, the results on the predictive accuracy of individual tests or groups of tests for reaching Driving Test standard also seemed to highlight the primary contribution of two of the four tests mentioned above, together with two additional tests. The individual tests, therefore, which seemed to discriminate best between drivers and nondrivers were the Picture Arrangement, Picture Completion, Pattern Copying and Logical Memory Tests. In addition, DFA indicated that the combined, weighted scores on 6 tests, the Logical Memory, Picture Arrangement, Pattern Copying, Picture Completion, Visual Reproduction and Token Tests, might discriminate between potential drivers and nondrivers as accurately as the scores of the 11 tests in this perceptual-cognitive battery.

The possibility that factors other than cognitive variables might contribute to whether a young person with spina bifida and hydrocephalus becomes a driver, has been mentioned in previous chapters. In the next section, therefore, an attempt is made to consider the relative contribution of sex, age, physical limitations and visual deficits to reaching Driving Test standard.

3. THE CONTRIBUTION OF NON-COGNITIVE FACTORS TO LEARNING TO DRIVE.

The results of the analyses of the perceptual-cognitive test scores of the small group of 14 learner drivers, described in the previous sections, indicated a more positive association between measured cognitive abilities and becoming a qualified driver, than analyses using larger groups. This increased degree of association may have been, at least, partly due to the small sample size. However, as has been mentioned in previous chapters, factors other than cognitive variables may contribute to whether young people with spina bifida and hydrocephalus learn to drive. This section reports the results of further analyses which considered the contribution of sex, age, physical limitations and visual deficits to passing the Driving Test in this group of 14 learner drivers.

Firstly, an inspection of the sex, age, mobility and visual defects of the driver and nondriver groups, detailed in Table 44, showed that the only marked difference was that based on sex. That is, the males were more successful than females in reaching Driving Test standard.

SUBGROUP	DRIVER	NONDRIVER
	n=6	n=8
SEX: male	6	3
female	0	5
AGE: less then 20 yrs	2	5
more than 20 yrs	4	3
MOBILITY: wheelchair	4	6
walker	2	2
SQUINT: present	5	5
absent	1	3
FIELD LOSS: present	4	4
absent	2	4

TABLE 44 : A comparison of the characteristics of 6 drivers and 8 nondrivers.

Two sets of statistical analyses were performed to further consider the nature and significance of these differences. Firstly, two Cluster Analyses (CA) provided a description of the common features of subgroups of individuals within the group of 14 learners. The first CA considered non-cognitive attributes of the group in terms of sex, age, mobility (walker or wheelchair user) and visual deficits (squint or field loss). The second CA considered cognitive functioning based on the scores of the five tests (Line Tracing, EFT, Token, Picture Completion and Logical Memory Tests) which, as a group, had most accurately predicted driver and nondrivers in the 39 Ss assessed for driving (as shown in Table 31). Following these descriptive analyses, two Discriminant Function Analyses were performed to assess the predictive validity of, firstly, non-cognitive variables only and, secondly a combination of non-cognitive and cognitive variables, for Driving Test success.

3.1. CLUSTER ANALYSES

As shown in Figure 16(a), Cluster Analysis based on the non-cognitive variables of sex, age, mobility and visual deficit, first defined a group of five wheelchairbound males over twenty years old with both a squint and visual field loss. A second cluster of 2 females with similar characteristics (excluding field loss) was also identified. Younger groups of wheelchair users, walkers and those with few visual deficits were gradually incorporated to form the total group of 14.

Also shown in Figure 16(b), are the results of CA on measures of cognitive functioning, as assessed by the Line Tracing, EFT, Token, Picture Completion and the Logical Memory Tests. The clusters identified were less definitive, although three main cognitive profiles were in evidence. These were grouped as follows:- (a) those who achieved high scores on all tests (2Ss) (b) those who achieved adequate scores on the visual-perceptual tests but performed poorly on the attention and memory tests (6Ss)

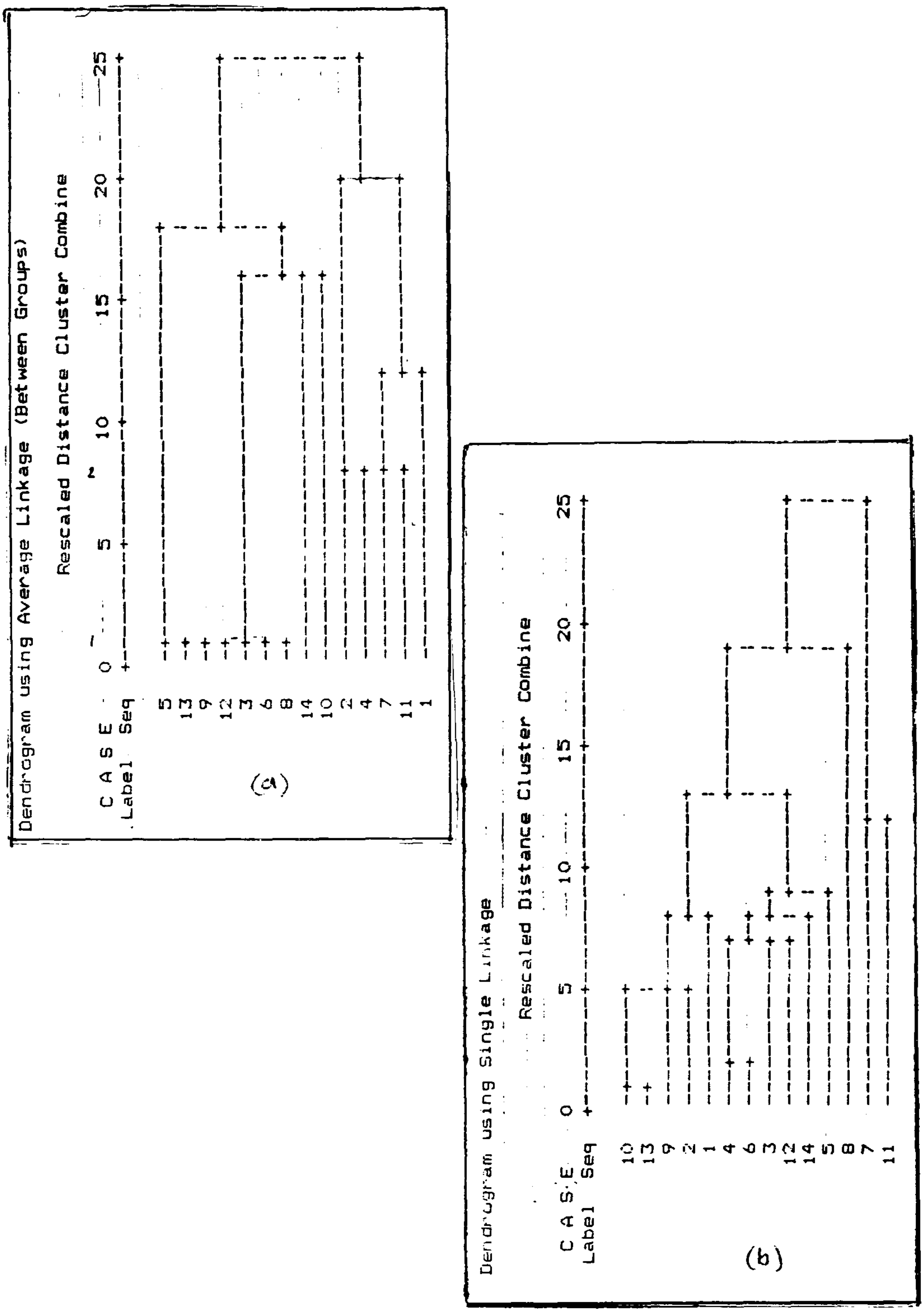


FIGURE 16 : Cluster analysis based on (a) visual and physical attributes (b) cognitive test scores.

Ss) (c) those who scored poorly on all tests (6 Ss).

Comparison of the groups identified by both sets of CAs indicated that the two Ss who achieved high scores on all tests (group (a)) were males under 20 years. Both were walkers and one had no visual defects. Both of these learners became drivers, along with 2 Ss from group (b) and 2 Ss from group (c). These additional 4 drivers were wheelchairbound males over 20 years old, all with visual defects. Of the nondrivers, all except two were wheelchairbound and demonstrated visual defects. The two exceptions were two young females, with minimal physical difficulties. No conclusions could, therefore, be drawn from these Cluster Analyses, regarding the contribution of non-cognitive variables to driving success.

3.2. DISCRIMINANT FUNCTION ANALYSES

The first DFA considered the predictive validity of sex, age, mobility and visual defects (squint and field loss) for achieving Driving Test standard. As shown in Table 45, not unexpectedly, bearing in mind the differences between the perceptual-cognitive test scores of males and females, highlighted in previous sections, sex correlated most highly with the one DF produced by the analysis.

The predictive equation accurately classified 92.9% of the group as drivers or nondrivers. Interestingly, all drivers

VARIABLE	STANDARDISED DISCRIMINANT FUNCTION CO-EFFICIENT
SEX	.57
AGE	.20
SQUINT	.16
FIELD LOSS	.11
MOBILITY	.06

TABLE 45 : Standardised discriminant function co-efficients for non-cognitive variables.

were successfully classified, but one nondriver was wrongly predicted as a driver. To assess the importance of being "male" or "female" for this group, sex was removed as a variable from the analysis. This reduced the predictive accuracy of the group of variables to 71.4%. A second DFA considered the same 5 non-cognitive variables of sex, age, mobility, squint and field loss in combination with the scores of the 14 Ss on the 5 perceptual-cognitive tests (Token, Picture Completion, EFT, Logical Memory and Visual Reproduction) found to be the best discriminators for driving, as discussed previously. As Table 46 shows, the variables which correlated most highly with the DF produced, were scores on four of the five tests (excluding EFT) and sex.

The predictive equation correctly classified all Ss as

VARIABLE	STANDARDISED DISCRIMINANT FUNCTION CO-EFFICIENT
LOGICAL MEMORY TEST	.44
SEX	.39
PICTURE COMPLETION TEST	.28
VISUAL REPRODUCTION TEST	.26
TOKEN TEST	.24
AGE	.14
EMBEDDED FIGURES TEST	.13
SQUINT	.10
FIELD LOSS	.08
MOBILITY	.04

TABLE 46 : Standardised discriminant function co-efficients for cognitive and non-cognitive variables for 14 SBH learner drivers.

drivers or nondrivers. This analysis confirmed the importance of good attentional and memory skills, together with accurate visual disembedding, for success in reaching Driving Test standard. Although sex was again a contributing factor to becoming a driver, this must be considered specific to the small sample studied, as males have not been identified as more likely to become drivers than males in analyses with other SBH groups in this study. It is of importance that the remaining non-cognitive variables did not contribute significantly to whether a person passed the Driving Test.

3.3. SUMMARY

The results of analyses presented in the previous sections have not, perhaps surprisingly, provided evidence to support the possibility that measurable factors other than those related to cognitive functioning, contributed significantly to whether the 14 SBH learners became qualified drivers. The superior male cognitive functioning, in this group, was not representative of the SBH population, as determined by the mean perceptual-cognitive test scores of the larger SBH groups considered in Chapters 7 and 8. When sex differences were excluded, the non-cognitive variables of age, mobility and visual defect were not found to be important for driving success.

The most significant finding from the DFAs, was that the four tests which have been emphasised as likely to be important for driving in other analyses, as reported previously, were again highlighted as those most likely to be predictive of driving success. These four tests, confirmed the contribution of, firstly, attentional and memory skills (Logical Memory, Visual reproduction and Token Tests) and, secondly, visual disembedding (Picture Completion Test) for efficient learning during the tuition period leading to success on the Driving Test.

It is important to note however, that although tuition throughout the driving courses closely followed sound teaching principles, control over the tuition programme was lost when pupils returned to their home areas. It was not considered possible, within the design of this study, to quantify the variables associated with driving instructor technique, nor those associated with "life circumstances", such as limited resources for cars and lessons. As will be discussed in the final chapter - although adequate cognitive skills may be an essential prerequisite for driving, these unquantifiable and sometimes unknown human variables may be the deciding factor in whether a person becomes a driver or not.

However, to assess the effect of one of these variables, teaching techniques, on learning, a small additional study was designed. Research has indicated that the learning difficulties of those those with spina bifida and hydrocephalus are partly due to specific memory deficit. However, as discussed in Chapter Six, this has not been reliably shown to be so. A further study was therefore designed to assess the ability of a subset of the SBH learner drivers to remember facts related to driving. This study is described in Chapter Ten.

CHAPTER TEN : DRIVING RELATED LEARNING

During the first of the three driving courses, differences in the "memory" ability of those taking part were evident during the classroom sessions. Although this first group only comprised 5 people, nearly all required one-to-one teaching for concentration to be maintained and for information to be organised in an "easy to learn" way. The review of the literature on the attention and memory skills of those with spina bifida and hydrocephalus, summarised in Chapter Six, indicated specific deficits in this area of cognition. It therefore seemed important to evaluate whether difficulty in remembering new information might contribute to success or failure in reaching Driving Test standard.

It is reasonable to assume that all those who were taking part in a driving course were well-motivated to learn. By controlling the content of driving related information and the method of presentation, it should therefore be possible to establish the nature and severity of memory impairment. A small, additional study was therefore planned for the second and third driving courses. The aim of this study was to assess memory for information related to the driving task, specifically, learning the meaning of road signs and remembering a route. This study is described in the following sections.

1. THE SAMPLE

The Ss were the 9 young people with spina bifida and hydrocephalus, who attended the second and third driving courses. They are described on page 218 as subject numbers 6-14.

2. DEVELOPMENT OF THE DRIVING RELATED MEMORY TESTS

2.1. ROAD SIGN MEMORY

The first set of tests was designed to assess the acquisition and retention of 18 pairs of road signs and their meanings.

TEST PRESENTATION

Twenty-four road signs, taken from the Highway Code, were individually mounted on cards (7 cms x 4.5cms) and randomly assigned to four sets. The instructions were - "Please try to remember the signs I am going to show you. Try to remember what each sign means as well as what it looks like". Cards from the first set of 6 were presented individually at the rate of 1 per 5 seconds. Each sign's meaning was given verbally during the 5 seconds. Immediate recall of sign meaning was tested by a paired associate method and the procedure repeated until a perfect trial was reached. The same procedure was used for set 2. Sets 1 and 2 were then combined for one recall trial. The same procedure was followed for set 3. Six days later, Ss were asked to sort sets 1-3 from set 4, to assess recognition memory for signs learnt. Sets 1-3 were then presented on a single trial for recall of sign meaning.

TEST SCORING

Each correctly remembered or recognised sign was scored 1.

2.2. LANDMARK AND ROUTE MEMORY

This second set of tests was designed to assess acquisition and retention of 6 "real-life" landmarks and a route.

TEST PRESENTATION

Each person was driven individually around a 1/2 mile route, 6 landmarks being pointed out (Figure 17). The task was to learn the landmarks and the route. The instructions were - "I am going to drive along a short route. I will point out several places on the way. Please try to remember the route and the places I point out". Each subject was driven three times around the designated route. At the end of three trials Ss were asked to name the 6 landmarks and then to direct the driver along the route. Six days later Ss were asked to recall the landmarks and to

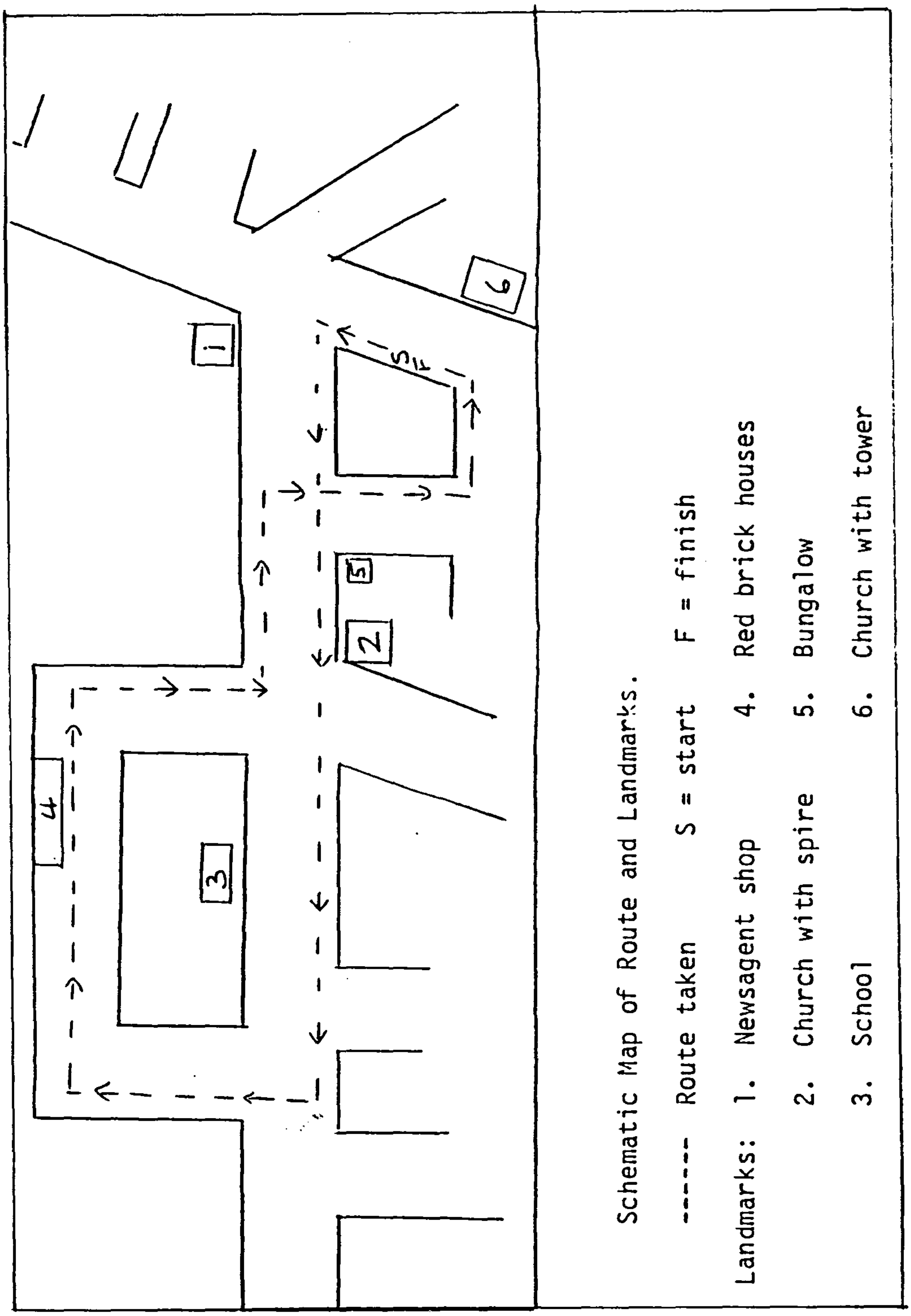


FIGURE 17 : Schematic map of route and landmarks.

direct the driver along the same route. Ss were then asked to make a freehand sketchmap of the route.

TEST SCORING

The number of landmarks remembered (maximum:6) and the number of correct turns on the route (maximum:8) were noted. The sketchmap of the route was scored for the inclusion of the 8 turns, figure of 8 shape, landmarks and additional correct information, such as street names. There was therefore no upper score limit on this test.

3. PROCEDURE

The first part of each set of driving related memory tests was given during the first week of the course. The second part, the "long-term" retention tests were given six days later.

4. RESULTS

The results on tests assessing the acquisition and retention of road signs are discussed first, followed by results relating to landmark and route memory. A final section considers two issues. Firstly, the question of whether there is any relationship between perceptual-cognitive test scores and memory for driving related information is addressed. The second issue centres on whether the 5 drivers and 4 nondrivers in this group of 9 Ss, demonstrated differences in the learning of new information related to driving.

4.1. ROAD SIGN MEMORY

As shown in Table 47, scores for the learning, recognition and recall of road signs indicated that this small group of 9 learner drivers was able to learn and retain new information related to road signs.

TEST	MEAN	SD	RANGE
ROAD SIGN LEARNING (no. of trials)	6.0	1.1	5-8
IMMEDIATE RECALL	16.2	2.0	12-18
DELAYED RECALL	15.1	2.0	12-17
SIGN RECOGNITION	13.1	2.9	10-18

TABLE 47 : Mean scores for learning, recognition and recall of road signs.

The minimum possible trials for learning the 18 signs was 4. Most Ss needed 1 or 2 additional trials before the signs and their meanings were learnt. However when all 18 signs were re-presented there was a 10% loss in the number of signs recalled. Six days later when Ss were asked to select the 18 signs from a group of 24, a mean number of 13

(72.8%) signs were correctly selected. When the 18 signs were presented for recall of meaning, a mean number of 15 (84%) were remembered. The results suggest therefore that memory for road signs, an integral part of learning to drive, was not significantly impaired in this group.

4.2. LANDMARK AND ROUTE MEMORY

The results on the landmark and route learning tasks, shown in Table 48, were also encouraging. At the end of the three learning trials, over 80% of the landmarks had been retained (5 out of 6) and over 90% of the turns on the route (7 out of 8). After a six day period there was a slight decrease in the route information retained, but with a few corrections, all learner drivers could remember the route to be followed.

TEST	MEAN	SD	RANGE
LANDMARK RECALL 1	5.2	1.1	3-6
LANDMARK RECALL 2	4.8	1.6	2-6
ROUTE LEARNING 1(errors)	.6	1.0	0-3
ROUTE LEARNING 2(errors)	.8	1.1	0-3
ROUTE DRAWING	8.9	2.6	6-12

TABLE 48 : Mean scores on landmark and route memory tests.

Two dimensional representation of the route was a difficult task for all learners. Particular difficulty was noted in realising (or remembering) the Figure of 8 shape of the route and placing the landmarks appropriately. These results closely parallel a study on the cognitive mapping abilities of those with SBH and their able-bodied controls (Simms,1987).

4.3. PERCEPTUAL-COGNITIVE TEST SCORES AND DRIVING RELATED LEARNING

Pearson correlation coefficients were calculated between scores on the 11 perceptual-cognitive tests and scores on the driving related learning tasks.

Not surprisingly, as shown in Table 49, in view of the large number of variables involved and the small number of subjects, there was a considerable amount of correlation between the test battery and the memory tasks. Consideration of the significant correlations ($p<.05$) between scores on the perceptual-cognitive tests and driving related learning scores suggested that although these measures might indicate immediate memory for new information (RECALL1), they were not likely to indicate retention over time (RECALL2) nor learning when the imput of information was less formal, as in the Landmark and Route Memory Tests.

Not unexpected, was the correlation between the Visual Reproduction Test and map drawing ability. Both tasks involved the ability to remember and spatially represent visually presented information.

TEST	TRIALS	RECALL1	RECALL2	RECOG
TOKEN TEST		.59		
PICTURE ARRANGEMENT TEST	.63	.79		
PICTURE COMPLETION TEST		.76*		
LETTER CANCELLATION (secs)				
ROAD MAP TEST		.64	.69	
EMBEDDED FIGURES TEST		.87**		
LINE TRACING TEST				.72
DIGIT SPAN TEST				
LOGICAL MEMORY TEST		.78*		
VISUAL REPRODUCTION TEST		.83*		

TABLE 49(a) : Pearson correlation coefficients between perceptual-cognitive test scores and road sign memory (p<.05) * p<.01 ** p<.001

4.4. SCORES OF DRIVERS AND NONDRIVERS

As shown in Table 50, when the scores of the 5 learners who became drivers and the 4 nondrivers were compared for differences in memory functioning, the only significant difference (p<.05) was for immediate recall of the 18 Road Signs. The drivers' mean score was 17.4 compared with the nondrivers' score of 14.8 ($p<.04$). On the Route Learning Test, although drivers remembered more correct turns and were more competent at drawing a map of the route, they were not significantly better than nondrivers.

TEST	LAND MARK1	LAND MARK2	ROUTE1	ROUTE2	MAP
TOKEN TEST					
PICTURE ARRANGEMENT TEST					
PICTURE COMPLETION TEST					.70
LETTER CANCELLATION (secs)			.73*	.75*	
ROAD MAP TEST					
EMBEDDED FIGURES TEST					.81*
LINE TRACING TEST					
DIGIT SPAN TEST	.80*				
LOGICAL MEMORY TEST					
VISUAL REPRODUCTION TEST	.58				.85*

TABLE 49(b) : Pearson correlation coefficients between perceptual-cognitive test scores and route learning tests ($p<.05$) * $p<.01$

5. SUMMARY

The learning and memory skills of the small group of 9 learner drivers indicated that immediate memory for new information was not significantly impaired, at least under optimum conditions. However, as there was no control data it was not possible to assess how those with SBH performed, compared with their able-bodied peers. Of most importance, however, was the finding that those who later passed the Driving Test remembered significantly more signs than those who did not become drivers. Of additional

TEST	DRIVERS	NONDRIVERS	p
	n=5	n=4	
ROAD SIGN LEARNING			
NUMBER OF TRIALS	5.6	6.5	ns
IMMEDIATE RECALL	17.4	14.8	.04
DELAYED RECALL (6 dys)	15.0	15.3	ns
SIGN RECOGNITION (6 dys)	14.0	12.0	ns
LANDMARK LEARNING			
IMMEDIATE RECALL	5.4	5.0	ns
DELAYED RECALL (6 dys)	5.0	4.5	ns
ROUTE LEARNING			
IMMEDIATE RECALL (errors)	.4	.8	ns
DELAYED RECALL (6 dys)	.4	1.3	ns
ROUTE DRAWING	9.8	7.8	ns

TABLE 50 : Driving related test scores for 5 drivers and 4 nondrivers.

significance was the finding that although perceptual-cognitive test scores might be associated with the ability to learn in the short-term, that is, when immediate recall is required, they were not associated with retention over time.

CHAPTER ELEVEN : CONCLUSION

This thesis has been concerned with the assessment of driving skills in young adults with spina bifida and hydrocephalus. It is now clear that a large number of these young people will never be able to drive. In some cases, this may be because they are ineligible to hold a provisional licence on medical or visual grounds. As far as physical difficulties are concerned, suitably adapted cars can compensate for most limitations. However, for others, the impediment to driving seems to lie in the perceptual or cognitive domain. These difficulties have formed the focus of this thesis. In particular, the question addressed has been whether it is possible to produce a battery of psychometric tests which can predict success or failure on a driving test.

The study began with a review of the findings from studies on cognitive deficit and driving and the cognitive functioning of SBH groups. This review revealed two main factors. Firstly, those likely to show learning difficulties were those with spina bifida and hydrocephalus and not those with spina bifida alone. Secondly, the review identified several areas of cognitive functioning as being of possible relevance in the assessment of suitability for driving. These were general intellectual functioning, visual-perceptual skill, attention and memory.

Over a period of several years, a battery of tests assessing these aspects of cognitive functioning was increased to include tests of figure-ground discrimination, spatial ability and visual tracking. As the work progressed, it became clear that the process of predicting driving success from cognitive tests was, in fact, limited. This conclusion was also one drawn by others in the field working with different populations. However, this work has not been in the least fruitless, as what did emerge was a much better view of what kinds of skills should be assessed and under what circumstances.

As far as the results are concerned, two main themes which might contribute to future research, will be pursued. The first theme concerns the role of cognitive assessment in prediction for driving. The second theme focuses on possible refinements to the battery of tests.

Considering, firstly, the role of cognitive assessment in the prediction of driving success. The results of this thesis have emphasised that prediction is a very complicated process and that factors other than cognitive ability need to be taken into account when learning to drive is considered. Of particular interest in relation to the restricted predictive nature of clinical tests, was the finding that the largest number of misclassifications was of those who should have become drivers, on the basis of test results, but did not. These nondrivers proved to be a diverse group. They included not only those who had failed to reach Driving Test standard, but also those who had not attempted to drive following assessment. Although in this study, numbers of Ss within subgroups were small, it did seem that those who could be considered "failures" were those who had begun tuition and given up before taking a Driving Test. It was clear from a comparison of subgroups, that there were likely to be potential drivers among those who had not started tuition.

The reasons why a person did not became a driver were not necessarily related to cognitive functioning and not always under a person's control. For example, a recent study on the SBH learner driver, completed since the studies reported in this thesis, demonstrated that the factors determining driving success were not, in fact, primarily related to individual physical or intellectual abilities at all, but to personal finance and local driving school facilities (Simms, 1989). In addition, although potential drivers appeared motivated to learn, they were often unable to organise themselves sufficiently to arrange finance for a car or for tuition. This would suggest that driving centres should be set up to provide a "total package" for driving.

Cognitive assessment therefore needs to be part of a more general model of prediction, with monitoring over a longer period of time than was possible for this thesis. Ideally, future research would be based around a long term study, which also involved the provision of suitably adapted cars and tuition for disabled learner drivers.

A second and separate issue relates to the components of the cognitive test battery itself. During the later stages of the development of the battery, it became clear that the individual tests chosen were not likely to discriminate adequately between potential drivers and nondrivers. The next step was, therefore, to consider groups of tests as possible predictors of driving success. Statistical analyses identified a subgroup of three tests, the Picture Completion, Logical Memory and Token Tests, as the best discriminator between those who became drivers and those who did not. Initially these three tests were chosen as measures of visual disembedding and memory. However, later, it was noted that all three tests also assessed the ability to discriminate between the essential and non-essential aspects of information. Clarification of the specific processes involved would, of course, require further investigation using tests specially designed to assess disembedding skills across modalities. An exciting venture would be to examine the disembedding skills of SBH drivers and nondrivers in real-life traffic situations.

The idea that assessment of the ability to follow instructions, retain new information and visually extract details from a complex background, were the skills which differentiated best between drivers and nondrivers, also gained support from the focussed study of 14 learner drivers. Furthermore, these abilities also differentiated between poor and competent performance on off-road manoeuvres at the end of ten hours tuition. The finding that driving instructors were also more accurate than many clinical tests in identifying driving potential in those they had taught for ten hours, came as a salutory lesson. Perhaps driving instructors should be allowed to provide a short course of "assessment" lessons for would - be drivers rather than these young people being offered a primarily clinical assessment for driving. Although more expensive, this method of assessment would have face validity for driving and, in addition, would be more in keeping with current approaches to assessment, which focus on the evaluation of learning ability.

In summary, the work presented in this thesis has not provided a definitive answer to the question of whether the ability to drive in young adults with spina bifida and hydrocephalus can be predicted from a battery of cognitive tests. However it has clarified a considerable number of theoretical and practical issues concerning how the subject can be approached in the future.

REFERENCES

ALLEN, T.M., LUNENFELD, H. and ALEXANDER, G.J. (1971) Driver information needs. Highway Research Record, 366, 102-115.

ANDERSON, E.M. (1975) Cognitive motor deficits in children with spina bifida and hydrocephalus with special reference to writing difficulties. Unpublished Ph.D. thesis, University of London.

ANDERSON, E.M. and PLEWIS, I. (1977) Impairment of a motor skill in children with spina bifida cystica and hydrocephalus : an exploratory study. British Journal of Psychology, 68, 61-70.

ANDERSON, E.M. and SPAIN, B. (1977) The Child with Spina Bifida. London : Methuen and Co. Ltd.

BADDELEY, A. (1986) Working Memory. Oxford : Science Publications.

BADELL-RIBERA, A., SHULMAN, K. and PADDOCK, N. The relationship of non-progressive hydrocephalus to intellectual functioning in children with spina bifida cystica. Paediatrics, 37, 787-793.

BARDACH, J. (1971) Psychological factors in the handicapped driver. Archives of Physical Medicine and Rehabilitation, 52, 328-332.

BARRETT, G. and THORNTON, C.L. (1968) Perceptual style and driver reactions. Journal of Applied Psychology, 52, 170-176.

BARTOSHESKY, L.E., HALLER, J., MICHAEL SCOTT, R. and WOSICK, C. (1985) Seizures in children with meningomyelocele. American Journal of Diseases in Children, 139, 400.

BAYSTON, R., LEUNG TERRESA, S.M., WILLIAMS, B.M. and HODGES, B. (1983) Bacteriological examination of removed cerebrospinal fluid shunts. Journal of Clinical Pathology, 36, 987-990.

BENDA, C.E. (1952) Developmental Disorders of Mentation and Cerebral Palsies. New York : Grune and Strutton Inc.

BENDER, L. (1946) Instructions for the Use of the Visual Motor Gestalt Test. New York : American Orthopsychiatry Association.

BENNETT, G.K. (1949) Test of Mechanical Comprehension. New York : Psychological Corporation.

BLACK, P.D. (1980) Ocular defects in children with cerebral palsy. British Medical Journal, 3, 487-88.

BLACK, P.M. (1979) Selective treatment of infants with myelomeningocele. Neurosurgery, 5, 334-338.

BOEHM, A.E. (1971) Boehm Test of Basic Concepts. New York : Psychological Corporation.

BOLLER, F. and VIGNOLA, L.A. (1966) Latent sensory aphasia in hemisphere-damaged patients : an experimental study with the Token Test. Brain, 89, 815-831.

BOYDSTUN, L.E., KESSEL, D.S., and MILLER, J.M. (1980) Assessment of perceptually disabled individuals' driving skills with a driving simulator. Proceedings of the Human Factors Society 24th. Annual Meeting.

BRITTAIN, M. (1969) The WPPSI : A Midlands study. British Journal of Educational Psychology, 39, 14-17.

BROADBENT, D. (1958) Perception and Communication. Oxford : Pergamon Press.

BROCKLEHURST, G., GLEAVE, J.R.W. and LEWIN, W. (1967) Early closure of myelomenigocele with special reference to leg movement. British medical Journal, 1, 666-669.

BRUNT, D. (1984) Apraxic tendencies in children with meningomyelocele. Adapted Physical Activity Quarterly, 1, 61-67.

CARR, J., HALLIWELL, M.D. and PEARSON, A.M. (1981) Educational attainments of spina bifida children attending ordinary or special schools. Zeitschrift fur Kinderchirurgie, 34, 364-370.

CARR, J., HALLIWELL, M.D. and PEARSON, A.M. (1984) The relationship of disability and school type to everyday life. Zeitschrift fur Kinderchirurgie, 39, Supplement II, 135-137.

CARR, J., PEARSON, A.M. and HALLIWELL, M.D. (1983) The GLC Spina Bifida Survey : Follow Up at 11 and 12 Years. London : ILEA.

CARR, J., PEARSON, A.M. and HALLIWELL, M.D. (1988) The contribution of psychological and motor factors to performance of a psychomotor task in children with spina bifida. Paper presented at the 32nd. Annual Meeting of the Society for Research into Hydrocephalus and Spina Bifida, Jerusalem, July 1988.

CHIARI, H. (1891) Uber veranderungen des kleinhirns in folge von hydrocephalie des grosshirns. Deutsch Med. Wschr., 27, 1172-1175.

CHIARI, H. (1896) Uber veranderungen des kleinhirns, des pons und der medulla oblongata in folge von congenitaler hydrocephalie des grosshirns. Denkschr. Akad. Wien., 63, 71-116.

CLEMENTS, D.B. and KAUSHAL, K. (1970) A study of the ocular complications of hydrocephalus and meningomyelocele. Transactions of the Ophthalmological Society of the United Kingdom, 90, 383-390.

COHEN, J. (1957) Factor-analytically based rationale for the Wechsler Adult Intelligence Scale. Journal of Consulting Psychology, 21, 451-457.

CONNOLLY, B., GUINEY, E.J. and FITZGERALD, R.J. (1987) CSF/shunt infections - the bane of our lives. Zeitschrift fur Kinderchirurgie, 42, Supplement 1, 13-14.

COSTA, L.D. (1975) The relation of visuo-spatial dysfunction to Digit Span performance in patients with cerebral lesions. Cortex, 11, 31-36.

CROFT, D. and JONES, R. (1987) The value of off-road tests in the assessment of driving potential of unlicensed disabled people. British Journal of Occupational Therapy, 50, 357-361.

CULL, C. and WYKE, M.A. (1984) Memory function of children with spina bifida and hydrocephalus. Developmental Medicine and Child Neurology, 26, 177-183.

DE RENZI, E. and VIGNOLO, L.A. (1962) The Token Test : a sensitive test to detect disturbances in aphasics. Brain, 85, 665-678.

DILLER, L., BEN-YISHAY, Y., GERSTMANN, L.J., GOODWIN, R., GORDON, W. and WEINBERG, J. (1974) Studies in Cognition and Rehabilitation in Hemiplegia. Rehabilitation Monograph No. 50. New York : New York University Medical Centre Institute of Rehabilitation Medicine.

DODD, K.D. (1984) Where should spina bifida children go to school? Zeitschrift fur Kinderchirurgie, 39, Supplement II, 129-131.

ELWOOD, J.M. and ELWOOD, J.H. (1980) Epidemiology of Anencephalus and Spina Bifida. Oxford : Oxford University Press.

EVANS, O., TEW, B. and LAURENCE, K.M. (1986) The fathers of children with spina bifida. Zeitschrift fur Kinderchirugie, 41, Supplement 1, 17-20.

FERGENSEN, P.E. (1971) Driving research program at Stevens Institute. Proceedings from the International Symposium on Psychological Aspects of Driver Behaviour held at Noordwijkerhout, The Netherlands 2-6th. August, Volume 1.

FITTS, P.M. (1954) The information capacity of discrete motor responses. Journal of Experiemental Psychology, 67, 103-112.

FROSTIG, M. (1966) Manual for the Marianne Frostig Developmental Test of Visual Perception. California : Consulting Psychologists' Press.

FROSTIG, M. and HORNE, D. (1964) The Frostig Program for the Development of Visual Perception : Teachers Guide. Chicago : Follet.

GASTON, H. (1985) Does the spina bifida clinic need an ophthalmologist? Zeitschrift fur Kinderchirurgie, 40, Supplement 1, 46-50.

GIANUTSOS, R. and KLITZNER, C. (1981) Computer Programs for Cognitive Rehabilitation. Bayport, New York: Life Science Associates.

GLUCKMAN, S. and BARLING, J. (1980) Effects of a remedial program on visual-motor perception in spina bifida children. Journal of Genetic Psychology, 136, 195-202.

GOLDBERG, S. (1985) Clinical Neuroanatomy Made Ridiculously Simple. Miami : MedMaster Inc.

GOLDEN, C.J., HANMEKE, T.A. and PARISCH, A.D. (1980) The Luria-Nebraska Neuropsychological Battery Manual. California : Western Psychological Sciences.

GOLPER, L., RAU, M. and MARSHALL, R. (1980) Aphasic adults and their decisions on driving. Archives of Physical Medicine and Rehabilitation, 61, 34-40.

GOODENOUGH, D.R. (1976) A review of individual differences in field dependence as a factor in auto safety. Human Factors 18, 53-62.

GORDON, N. (1977) Normal pressure hydrocephalus and arrested hydrocephalus. Developmental Medicine and Child Neurology, 19, 540-542.

GRANT, D.W., GOLDBERG, C., GUINEY, E.J. and FITZGERALD, R.J. (1986) Should the tradition of right cerebral hemisphere shunting still prevail? Zeitschrift fur Kinderchirurgie, 41, Supplement 1, 3-4.

GRIFFITHS, R. (1954) The Abilities of Babies. London : University of London Press.

HAGBERG, B. (1962) The sequelae of spontaneously arrested hydrocephalus. Developmental Medicine and Child Development, 4, 583-587.

HALLIWELL, M.D., CARR, J.G., PEARSON, A.M. (1980) The intellectual and educational functioning of children with neural tube defects. Zeitschrift fur Kinderchirurgie, 31, 375-381.

HAMMOCK, M.K., MILHORAT, T.H. and BARON, I.S. (1976) Normal pressure hydrocephalus in patients with myelomeningocele. Developmental Medicine and Child Neurology,18, Supplement 37, 55-68.

HARCOURT, R.B. (1979) Optic Atrophy in Childhood. In Visual Handicap in Children (Ed.) Smith, V. and Keen, J., London : Heinemann.

HORN, D.G., LORCH, E.P., LORCH JUNIOR, R.F. and CULATTA, B. (1985) Distactibility and vocabulary deficits in children with spina bifida and hydrocephalus. Developmental Medicine and Child Neurology, 27, 713-720.

HUNT, G.M., LEWIN, W., GLEAVE, J. and GAIRDNER, D. (1973) Predictive factors in open myelomenigocele with special reference to sensory level. British Medical Journal, 4, 197-201.

JONES, R., GIDDENS, H. and CROFT, D. (1983) Assessment and training of brain-damaged drivers. The American Journal of Occupational Therapy, 37, 756-760.

KAUFMAN, A.S. (1980) Issues in Psychological Assessment : Interpreting the WISC-R Intelligently. In Blattey, B. and Kazdin, A.E. (Eds) Advances in Clinical Child Psychology Volume 3. New York : Plenum Press.

KEY, E.A.H. and RETZIUS, G. (1875) Studien in der Anatomie des Newemsystems und des Bindegewebes. Stockholm : Samson and Wallin.

KORTELING, H. (1988) Reaction time and driving capabilities of brain-injured and elderly drivers. In Road User Behaviour:Theory and Research (Ed.) Rothengatter, T. and de Bruin, R. Traffic Research Centre, University of Groningen, The Netherlands.

KRAMER, U. and ROHR, G. (1982) A model of driver behaviour. Ergonomics, 25, 891-907.

LAURENCE, K.M. (1969) Neurological and intellectual sequelae of hydrocephalus. Archives of Neurology, 20, 73-81.

LAURENCE, K.M. (1985) The apparently declining prevalence of neural tube defect in two counties in South Wales over three decades illustrating the need for continuing action and vigilance. Zeitschrift fur Kinderchirurgie, 40, Supplement 1, 58-60.

LAURENCE, K.M. (1989) A declining incidence of neural tube defects in the U.K. Zeitschrift fur Kinderchirurgie, 44, Supplement 1, 51.

LAURENCE, K.M. and COATES, S. (1962) The natural history of hydrocephalus. Archives of Disease in Childhood, 37, 345-362.

LAURENCE, K.M. and COATES, S. (1967) Spontaneously arrested hydrocephalus : results of the re-examination of 82 survivors from a series of 182 unoperated cases. Developmental Medicine and Child Neurology, Supplement 13, 4-13.

LAURENCE, K.M. and TEW, B.L. (1967) Follow-up of 65 survivors from 425 cases of spina bifida born in South Wales between 1956 and 1962. Developmental Medicine and Child Neurology, Supplement 13, 1-3.

LAURENCE, K.M. and TEW, B.J. (1971) Natural history of spina bifida cystica and cranium bifidum cystica. Major central nervous system malformations in South Wales. Part IV. Archives of Disease in Childhood, 46, 127-138.

LEZAK, M. (1979) Neuropsychological Assessment. Oxford University Press.

LIKERT, R. and QUASHA, W.H. (1948) Revised Minnesota Paper Form Board Test. New York : Psychological Corporation.

LONTON, A.P. (1976) Hand preference in children with myelomeningocele and hydrocephalus. Developmental Medicine and Child Neurology, 18, Supplement 37, 143-149.

LONTON, A.P. (1977) Location of the myelomeningocele and its relationship to subsequent physical and intellectual abilities in children with myelomeningocele associated with hydrocephalus. Zeitschrift fur Kinderchirugie, 22, 510-518.

LONTON, A.P. (1979) The relationship between intellectual skills and the computerised axial tomograms of children with spina bifida and hydrocephalus. Zeitschrift fur Kinderchirurgie, 28, 368-373.

LONTON, A.P. (1981) The integration (mainstreaming) of spina bifida children into ordinary schools. Zeitschrift fur Kinderchirurgie, 34, 356-364.

LONTON, A.P. (1982) Prediction of intelligence in spina bifida neonates. Zeitschrift fur Kinderchirugie, 37, 172-174.

LONTON, A.P. (1985) Gender and spina bifida - some misconceptions. Zeitschrift fur Kinderchirugie, 40, Supplement 1, 34-36.

LONTON, A.P., BARRINGTON, N.A. and LORBER, J. (1975) Lacunar skull deformity related to intelligence in children with myelomeningocele and hydrocephalus. Developmental Medicine and Child Neurology, 17, Supplement 35, 55-64.

LONTON, A.P., COLE, M.S. and MERCER, J. (1986) The integration of spina bifida children - are their needs being met? Zeitschrift fur Kinderchirurgie, 41, 45-47.

LONTON, A.P., LOUGHLIN, A.M. and O'SULLIVAN, A.M. (1984) The employment of adults with spina bifida. Zeitschrift fur Kinderchirurgie, 39, Supplement II, 132-134.

LONTON, A.P., O'SULLIVAN, A.M. and LOUGHLIN, A.M. (1983) Spina bifida adults. Zeitschrift fur Kinderchirurgie, 38, Supplement II, 110-112.

LONTON, A.P. and SKLAYNE, K. (1980) The relationship between social class and educational, psychological and physical aspects of spina bifida and hydrocephalus. Zeitschrift fur Kinderchirurgie, 31, 369-375.

LOO, R. (1978) Individual differences and the perception of traffic signs. Human Factors, 20, 65-74.

LORBER, J. (1971) Results of treatment of myelomeningocele: an analysis of 524 unselected cases with special reference to possible selection for treatment. Developmental Medicine and Child Neurology, 13, 279-303.

MACQUARRIE, T.W. (1953) MacQuarrie Test for Mechanical Ability. New York : McGraw Hill.

MAGENDIE, F. (1825) Memoire sur le liquide qui se trouve dans le crane et l'epine de l'homme et des animaux. Journal of Physiology and Experimental Pathology, 5, 27-37.

MAWDSLEY, T., RICKHAM, P.P. and ROBERTS, J.R. (1967) Long term results of early operation of open myelomeningoceles and encephaloceles. British Medical Journal, 1, 663-666.

McFIE, J. (1960) Psychological testing in clinical neurology. Journal of Nervous and Mental Diseases, 131, 383-393.

McKNIGHT, A.J. and ADAMS, B.B. (1971) The development of driver education objectives through an analysis of the driving task. Human Resources Research Organisation Professional Paper 4-71, Virginia USA.

MILLER, E. and SETHI, L. (1971) The effect of hydrocephalus on perception. Developmental Medicine and Child Neurology, Supplement 25, 77-81.

MINNS, R.A., SOBKOWIAK, C.A., SKARDOUTSOU, A., DICK, K., ELTON, R.A., BROWN, J.A. and FORFAR, J.A. (1977) Upper limb function in spina bifida. Zeitschrift fur Kinderchirugie, 22, 493-505.

MITTLER, P. (Ed) (1970) The Psychological Assessment of Mental and Physical Handicaps. London : Methuen and Co.

MONEY J., ALEXANDER, D. and WALKER JUNIOR, H.T. (1965) Manual for a Standardised Road Map Test of Direction Sense. Baltimore : John Hopkins University Press.

MORGAGNI, G.N. (1761) The Seats and Causes of Diseases Investigated by Anatomy. London : Millar and Cadell.

MOURANT,R. and ROCKWELL, T. (1970) Matching eye movement patterns to the visual scene in driving: an exploratory study. Human Factors, 12, 81-87.

NOURI, F.M., TINSON, D.J. and LINCOLN,N.B. (1987) Cognitive ability and driving after stroke. International Disability Studies, 9, 110-115.

NULSEN, F.E. and SPITZ, E.B. (1952) Treatment of hydrocephalus by direct shunt from ventricle to jugular vein. Surgery Forum, 2, 399-403.

OFFICE OF POPULATION CENSUSES AND SURVEYS (1990) Congenital Malformation Statistics: Notification 1988. Series MB3 No.4 HMSO.

PARSONS, J.G. (1972) Assessment of aptitudes in young people of school-leaving age handicapped by hydrocephalus or spina bifida cystica. Developmental Medicine and Child Neurology, 14, Supplement 27, 101-107.

PEARSON, A., CARR, J. and HALLIWELL, M. (1985) The self concept of adolescents with spina bifida. Zeitschrift fur Kinderchirurgie, 40, Supplement 1, 27-30.

PEARSON, A., CARR, J. and HALLIWELL, M. (1988) The handwriting of children with spina bifida. Zeitschrift fur Kinderchirurgie, 43, Supplement II, 40-42.

PUDENZ, R.H., RUSSEL, F.E., HURD, A.H., SHELDEN, C.H. (1957) Ventriculo-auriculostomy. A technique for shunting cerebrospinal fluid into the right auricle. Preliminary report. Journal of Neurosurgery, 14, 171-179.

PURI, P., MALONE, M. and GUINEY, E.J. (1977) Primary hydrocephalus: the effect of timing of first valve insertion, valve revision and the nature of the revisions on intelligence. Zeitschrift fur Kinderchirurgie, 22, 506-510.

QUIGLEY, F.L. and DELISA, J.A. (1983) Assessing the driving potential of cerebral vascular accident patients. The American Journal of Occupational Therapy, 37, 474-478.

RAFFLE, A. (ED) (1985) Medical Aspects of Fitness to Drive. A Guide for Medical Practitioners. The Medical Commission on Accident Prevention.

RAVESTEIN, R., VELING, I. and GAILLARD, A. (1982) The driving skill of rehabilitants with a diffuse traumatic injury of the brain: a preliminary approach. TNO Report No. IZF 1982-16, The Netherlands.

REY, A. (1964) L'Examen Clinique en Psychologie. Paris : Presses Universitaires de France.

RICHARDSON, J.T.E. (1978) Memory and intelligence following spontaneously arrested hydrocephalus. British Journal of Social and Clinical Psychology, 17, 261-267.

ROBINSON, R.O., LIPPOLD, T. and LAND, R. (1986) Body schema : does it depend on bodily-derived sensations? Developmental Medicine and Child Neurology, 28, 49-52.

ROSVOLD, H.E., SARASON, J., BRANSOME, E.D. and BECK, L.H. (1956) A continuous performance test of brain damage. Journal of Consulting Psychology, 20, 343-350.

RUMAR, K. (1982) The human factor in road safety. Proceedings of the 11th. ARRB Conference Volume II.

RUTTER, M., GRAHAM, P. and YULE, W. (1970) A Neuropsychiatric Study in Childhood. Clinics in Developmental Medicine 35/36.

SAND, P.L., TAYLOR, N., RAWLINGS, M. and CHITNIS, S. (1973) Performance of children with spina bifida manifesta on the Frostig Developmental Test of Visual Perception. Perceptual and Motor Skills, 37, 539-546.

SATTLER, J. (1982) Assessment of Children's Intelligence and Special Abilities. Second Edition. USA: Allyn and Bacon.

SCHWALBE, E. and GREDIG, M. (1906) Uber entwick lungsstorungen des kleinhirns, hirnstamms und halsmarks bei SB (Arnold'sche und Chiari'sche missbildung). Beitr. Path. Anat. (Jena), 40, 182-194.

SCHWEITZER, J.R., GOUVIER, W.D., HORTON, C.R., MAXFIELD, M., SHIPP, M. and HALE Jr.,P.N. (1988) Assessment of the cognitive components of driving performance among disabled individuals. In Ergonomics in Rehabilitation (Ed.) Mihal, A. and Kaewowski, W. Taylor and Francis, New York.

SHARRARD, W.J.W., ZACHARY, R.B., LORBER, J., and BRUCE, A.M. (1963) A controlled trial of immediate and delayed closure of spina bifida cystica. Archives of Disease in Childhood, 38, 18-22.

SHINAR, D. (1978) Field dependence and driver visual search behaviour. Human Factors, 20, 553-559.

SHOPTAUGH, C.F. and WHITAKER, L.A. (1984) Verbal response times to directional traffic signs embedded in photographic street scenes. Human Factors, 26, 235-44.

SHURTLEFF, D.B. (1986) Meningomyelocele : a new or a vanishing disease. Zeitschrift fur Kinderchirurgie, 41, Supplement 1, 5-9.

SIMMS, B. (1987) The route learning ability of young people with spina bifida and hydrocephalus and their able-bodied peers. Zeitschrift fur Kinderchirurgie, 42, Supplement 1, 53-56.

SIMMS, B. (1989) Driver education : the needs of the learner driver with spina bifida and hydrocephalus. Zeitschrift fur Kinderchirugie, 44, Supplement 1, 35-37.

SIMMS, B. and NICHOLLS, W. (1988) The Learner Driver with Spina Bifida and Hydrocephalus : Notes for Driving Instructors. London : ASBAH.

SIVAK, M., HILL, C., HENSON, D., BUTLER, B., SILBER, S. and OLSON, P. (1984) Improved driving performance following perceptual training in persons with brain damage. Archives of Physical Medicine and Rehabilitation, 65, 163-167.

SIVAK, M., HILL, C. and OLSON, P. (1984a) Computerised video tasks as training techniques for persons with brain damage : a pilot evaluation. International Journal of Rehabilitation Research, 7, 389-398.

SIVAK, M., OLSON, P., KEWAN, D., WON, H. and HENSON, D. (1981) Driving and perceptual/cognitive skills : behavioural consequences of brain damage. Archives of Physical Medicine and Rehabilitation, 62, 476-483.

SKLAYNE, K. (1981) The effects of selective surgery on the self-concept and attainments of children with spina bifida and hydrocephalus. Zeitschrift fur Kinderchirurgie, 34, 352-356.

SMYTH, B.T., PIGGOT, J., FORSYTH, W.I. and MERRETT, J.D. (1974) A controlled trial of immediate and delayed closure of myelomeningocele. Journal of Bone and Joint Surgery, 56B, 297-304.

SPAIN, B. (1969) Estimating the future school population of spina bifida children within London. GLC Research and Intelligence Unit Quarterly Bulletin, 7, 18-25.

SPAIN, B. (1970) Spina bifida survey. GLC Research and Intelligence Unit Quarterly Bulletin, 12, 5-12.

SPAIN, B. (1972) Verbal and performance ability in pre-school spina bifida children. Developmental Medicine and Child Neurology, Supplement 27, 155.

SPAIN, B. (1973) Treatment patterns and outcome for spina bifida within Greater London (Summary). Developmental Medicine and Child Neurology, Supplement 29, 115.

SPAIN, B. (1974) Verbal and performance ability in pre-school children with spina bifida. Developmental Medicine and Child Neurology, 16, 773-780.

SPELLACY, F.J. and SPREEN, O. (1969) A short form of the Token Test. Cortex, 5, 390-397.

STARK, G. and DRUMMOND, M. (1971) The spinal cord lesion in myelomeningocele. Developmental Medicine and Child Neurology, Supplement 25, 1-14.

STAUGHTON, G.C. and STORIE, V.J. (1977) Methodology of an In-Depth Accident Investigation Survey. TRRL Report LR 768, Crowthorne, Berks.

STELLMAN, G.R., BANNISTER, C.M. and HILLIER, V. (1986) The incidence of seizure disorder in children with acquired and congenital hydrocephalus. Zeitschrift fur Kinderchirurgie, 41, Supplement 1, 38-41.

STEPHEN, E. (1963) Intelligence levels and educational status of children with myelomeningocele. Developmental Medicine and Child Neurology, 5, 572-576.

STOKX, L.C. and GAILLARD, A.W.K. (1986) Task and driving performance of patients with a severe concussion of the brain. Journal of Clinical and Experimental Neuropsychology, 8, 421-436.

STORES, G., HART, J. and PIRAN, N. (1978) Inattentiveness in schoolchildren with epilepsy. Epilepsia, 19, 169.

SULLIVAN, R.A., CELIKYOL, F., COMMAROTO, L. (1975) Pre-driving Evaluation for the Brain-Damaged Patient. Kessler Institute for Rehabilitation, West Orange, New Jersey.

SUMMALA, H. (1988) Risk control is not risk adjustment: the zero-risk theory of driver behaviour and its implications. Ergonomics, 31, 491-506.

TERMAN, L.M. and MERRILL, M.R. (1960) Stanford-Binet Intelligence Scale. Boston : Houghton Mifflin. London : G.G.Harrap.

TEW, B. (1979) The "cocktail party syndrome" in children with hydrocephalus and spina bifida. British Journal of Disorders of Communication, 14, 89-101.

TEW, B.J., EVANS, R., THOMAS, M. and FORD, J. (1985) The results of a selective surgical policy on the cognitive abilities of children with spina bifida. Developmental Medicine and Child Neurology, 27, 606-614.

TEW, B.J. and LAURENCE, K.M. (1972) The ability and attainments of spina bifida patients born in South Wales between 1956-1962. Developmental Medicine and Child Neurology, 14, Supplement 27, 124-131.

TEW, B.J. and LAURENCE, K.M. (1973) Mothers, brothers and sisters of spina bifida patients. Developmental Medicine and Child Neurology, 15, Supplement 29, 69-76.

TEW, B.J. and LAURENCE, K.M. (1975) The effects of hydrocephalus on intelligence, visual perception and school attainment. Developmental Medicine and Child Neurology, 17, Supplement 35, 129-134.

TEW, B.J. and LAURENCE, K.M. (1976) The effects of admission to hospital and surgery on children with spina bifida. Developmental Medicine and Child Neurology, 18, Supplement 37, 119-125.

TEW, B.J. and LAURENCE, K.M. (1978) Ocular defect, intellectual and motor performance in children with spina bifida cystica. Zeitschrift fur Kinderchirugie, 25, 324-330.

TEW, B.J. and LAURENCE, K.M. (1979) The clinical and psychological characteristics of children with the "cocktail party" syndrome. Zeitschrift fur Kinderchirurgie, 28, 360-361.

TEW, B.J. and LAURENCE, K.M. (1983) Spina bifida children's intelligence test scores at school entry and at school leaving. Child Care Health Development, 9, 13-17.

TEW, B.J., LAURENCE, K.M. and RICHARDS, A. (1980) Inattention among children with hydrocephalus and spina bifida. Zeitschrift fur Kinderchirurgie, 31, 381-386.

TEW, B.J., LAURENCE, K.M. and SAMUEL, P. (1974) Parental estimates of the intelligence of their physically handicapped child. Developmental Medicine and Child Neurology, 16, 494-500.

THOMPSON, R.R., REPA, B.S. and LEUCHT, P.M. (1980) Evaluating the Driving Potential of the Handicapped Using a Simulator. SAE Paper Series 800421. SAE Inc., Pennsylvania.

TIFFIN, J.H. (1968) Purdue Pegboard. Chicago : Science Research Associates.

TREAT, J.R., TUMBAS, N.S., McDONALD, S.T., SHINAR, D., HUME, R.D., MAYER, R.E., STANISFER, R.L. and CASTELLAN, N.J. (1977) Tri-level Study of the Causes of Traffic Accidents. Report No. DOT-HS-034-3-535-77 (TAL) Indiana University.

TROMP, C.N. and VAN DEN BURG, W. (1982) Verbal memory impairment in treated hydrocephalic children. Zeitschrift fur Kinderchirurgie, 37, 175-178.

TUKEY, J.W. (1953) The Problem of Multiple Comparisons. Princetown University.

TURNER, A. (1986) Upper limb function of children with myelomenigocele. Developmental Medicine and Child Neurology, 28, 790-798.

VAN FOREEST, P. (1587) Observationum medicinalium libri tres, de capitas et cerebri morbis ac symptomatis; Ex Off Platiniana Raphelengii, Leiden.

VAN GOOL, J.D. and VAN GOOL, A.B. (1986) A Short History of Spina Bifida. Society for Research into Hydrocephalus and Spina Bifida. Utrecht : Van Rossum B.V.

VAN WOLFFELAAR, P., VAN ZOMEREN, A.H., BROUWER, W.H. and ROTHENGATTER, T. (1988) Assessment of fitness to drive of brain-damaged persons. In Road User Behaviour: Theory and Research (Ed.) Rothengatter, J.A. and de Bruin, R.A.

VAN ZOMEREN, A.H., BROUWER,W.H. and MINDERHAND, J.M. (1987) Acquired brain damage and driving : a review. Annals of Physical and Medical Rehabilitation, 68, 697-705.

VAN ZOMEREN, A.H., BROUWER, W.H., ROTHENGATTER, J.A. and SNDEK, J.W. (1988) Fitness to drive after recovery from severe head injury. Annals of Physical and Medical Rehabilitation, 69, 90-96.

WALLACE, S.J. (1973) The effect of upper-limb function on mobility of children with myelomeningocele. Developmental Medicine and Child Neurology, 15, Supplement 29, 85-91.

WECHSLER, D. (1939) Measurement of Adult Intelligence. Baltimore : Williams and Williams.

WECHSLER, D. (1945) A standardised memory scale for clinical use. Journal of Psychology, 19, 87-95.

WECHSLER, D. (1949) Wechsler Intelligence Scale for Children. New York : Psychological Corporation.

WECHSLER, D. (1955) Wechsler Adult Intelligence Scale. New York : Psychological Corporation.

WECHSLER, D. (1967) Wechsler Pre-School and Primary Scale of Intelligence. New York : Psychological Corporation.

WECHSLER, D. (1974) Wechsler Intelligence for Children - Revised. New York : Psychological Corporation.

WECHSLER, D. (1981) Wechsler Adult Intelligence Scale - Revised. Ohio : Psychological Corporation.

WHYTT, R. (1768) Observations on the Dropsy of the Brain. Edinburgh : Balfour, Auld and Smellie.

WILLIAMS, J.R. (1971) A study of the relationship between three dimension spatial relations ability and driving performance: a comparison of performance on the three dimensional Embedded Figures Test and on-the-job driving performance of telephone company drivers. Ph.D. thesis, New York University.

WILSON, T. and SMITH, T. (1983) Driving after stroke. International Rehabilitation Medicine, 5, 170-177.

WITKIN, H.A., OLTMAN, P.K., RASKIN, E. and KARP, S.A. (1971) Manual of the Embedded Figures Test. California : Consulting Psychologists' Press.

YULE, W., BERGER, M., BUTLER, S. NEWHAM, W. and TIZARD, J. (1969) The WPPSI : An empirical evaluation with a British sample. British Journal of Educational Psychology, 39, 1-14.

APPENDIX I : GLOSSARY OF MEDICAL TERMS

ANENCEPHALY : a condition related to spina bifida in which the exterior part of the brain fails to develop, resulting in early death.

APRAXIA : an inability to plan and organise movements in space.

ARNOLD-CHIARI MALFORMATION : an abnormality associated with spina bifida myelomeningocele, in which part of the brain stem and cerebellum protrude downwards through the upper end of the spinal canal.

CEREBROSPINAL FLUID : a clear fluid produced within the brain ventricles, which bathes and protects the brain and spinal cord.

ENCEPHALOCELE : a condition similar to spina bifida, where the defect is in the fusion of the skull and resulting herniation of the tissues.

FORAMEN MAGNUM : a hole in the base of the skull through which the nerves of the spinal column ascend and descend from the brain.

HOMONYMOUS HEMIANOPIA : a visual field defect in which half the field is missing.

HYDROCEPHALUS : a condition which develops when an abnormally large amount of cerebrospinal fluid collects in the ventricles of the brain.

MENINGES : the membranes covering the brain and spinal cord, which also carry the blood supply for the nervous tissue.

MENINGOCELE : a form of spina bifida aperta in which the meninges, but not the spinal cord, herniate to form a cyst.

MYELOMENINGOCELE : the most serious form of spina bifida aperta in which the spinal cord itself is abnormal, protruding with the meninges into the cyst.

NEURAL TUBE DEFECT : a term used to cover any condition in which the spine fails to develop normally eg. spina bifida, anencephaly.

NYSTAGMUS : involuntary eye-movements causing a jerky or jumping image.

PARAPLEGIA : a condition in which both lower limbs are paralysed.

QUADRANT DEFECT : a visual field defect in which a quarter of the visual field is missing.

SHUNT : a device used to control hydrocephalus. It consists of a thin plastic tube running from one of the brain ventricles to another part of the body where the excess CSF can be reabsorbed into the blood stream. A valve controls the direction and rate of flow of the fluid.

SPINA BIFIDA : a group of developmental defects in which part of the spine fails to fuse.

SPINA BIFIDA APERTA : the most serious form of spina bifida in which part of the meninges herminates to form a cyst filled with cerebrospinal fluid. Also called Spina Bifida Cystica.

SPINA BIFIDA OCCULTA : the least severe form of spina bifida in which the spine is "split" at some point, but the underlying structures are normal.

STRABISMUS or SQUINT : a muscle imbalance which prevents the eyes co-ordinating to produce binocular single vision.

VENTRICLES : cavities within the brain around which the nerve tissue is folded and which produce cerebrospinal fluid.

VERTEBRAE : the bones of the spinal column which enclose the spinal cord.

APPENDIX II : LONGITUDINAL STUDIES

During the 1960s and early 1970s three main centres of "expertise" produced most of the research literature on spina bifida and hydrocephalus. These centres were based in South Wales, Greater London and Sheffield. As each centre has taken a different approach to the study of spina bifida and hydrocephalus, the sections below describe the aims and major publications separately for each centre.

1. SOUTH WALES STUDY

This study began in the mid 1960s and represents an attempt to follow-up all cases of spina bifida meningocele, myelomeningocele and encephalocele born since 1956 in an area in South Wales. This area extends from the Vale of Glamorgan, to include the mining valleys of Monmouthshire and Glamorgan, to the Neath Valley. The towns of Cardiff, Newport, Barry, Penarth and Neath are excluded.

The primary researchers since the inception of the South Wales Study have been Brian Tew and Michael Laurence. It can be seen from Table 51 that the emphasis in the earlier papers was on medical factors and the effect of disability on overall intellectual functioning. The second group of studies is more broadly based, but concentrates primarily

INDEX POPULATION	AUTHORS	TOPIC
67 untreated survivors with meningocele, myelomeningocele or encephalocele, with or without hydrocephalus born 1956-62	LAURENCE AND TEW (1967)	Follow-up of 65 survivors
	LAURENCE AND TEW (1971)	Natural history of spina bifida and cranium bifidum
	TEW AND LAURENCE (1972)	Ability and attainments
	TEW ET AL (1974)	Parental estimates of intelligence

TABLE 51(a) : Major reports from the South Wales Longitudinal Study divided by Index Population : Untreated cases 1956-62.

on the effect of handicap on family and social life.

This series of studies is the most comprehensive of the three longitudinal investigations, although can, on occasion, be criticised for not presenting sufficient details on the groups concerned. This is mainly seen in the earlier studies eg. Laurence and Tew (1971), Tew and Laurence (1972), where it is not always clear which groups have spina bifida only or spina bifida with hydrocephalus. Later reports on the second younger group, born 1964-66, considered the effects of hydrocephalus and surgical treatment more carefully eg. Tew and Laurence (1975, 1978).

INDEX POPULATION	AUTHORS	TOPIC
59 unselected survivors born 1964-66. 59 controls matched on sex, locality, place in family and social class	TEW AND LAURENCE (1973)	Mothers, brothers and sisters of SB children
	TEW AND LAURENCE (1975)	Intelligence, visual perception and school attainment
	TEW AND LAURENCE (1976)	Hospital admission and surgery
	TEW AND LAURENCE (1978)	Ocular defect
	TEW (1979)	The "cocktail party syndrome"
	TEW AND LAURENCE (1983)	Academic achievements
	EVANS ET AL (1986)	Fathers of SB children

TABLE 51(b) : Major reports from the South Wales Longitudinal Study divided by Index Population : Unselected cases 1964-66.

A later important paper (Tew et al, 1985) considered a third group of children born 1973-78, following the introduction of selection for surgery in Cardiff.

2. GREATER LONDON SURVEY

This study was instigated in 1967 by the Research and Intelligence Unit of the Greater London Council (GLC). The aim was to determine the school provision requirements of children with spina bifida in all the London Boroughs (except Bexley). The primary researcher at this time was Bernie Spain, who outlined the three main studies of this survey as follows (Spain, 1969):-

(i) A prevalence study of all cases of spina bifida under the age of 16 living in the GLC at the end of 1966.

(ii) An incidence study to determine the annual figures of those born with a neural tube defect ie. spina bifida and anencephaly between April 1965 and March 1969.

(iii) A follow-up study of children born with spina bifida between April 1967 and March 1969.

168 children formed the index population for the longitudinal study, representing 43% of those born in the period 1967-69. A policy of "total care" was in force in the GLC during this period and all children received surgical or other treatment at birth and thereafter as required. This group was regularly seen by Spain until their sixth birthday when they had been in school for six terms (Spain, 1972, 1974). The publications from this part

of the study are listed in Table 52, section (i). In addition, Spain, in collaboration with Anderson, collated the research findings from this and other studies in a book, designed to provide information and practical help to parents and teachers of children with spina bifida and hydrocephalus (Anderson and Spain, 1977).

The second stage of the study was carried out by Janet Carr and her colleagues, who considered the same group of children at eleven and twelve years, at the end of primary school. This stage considered intellectual and academic functioning in relation to physical disability, hydrocephalus and the type of schooling. In addition, social and emotional development, particularly within the family setting, was investigated. Details of this comprehensive report by Carr et al (1983), together with publications on selected aspects of functioning are given in Table 52, section (ii).

3. SHEFFIELD STUDY

Tony Lonton has adopted a different approach in the study of those born with spina bifida and hydrocephalus in the Sheffield and Manchester areas. Over the years a computer database has been developed, holding information on over 2000 cases. This includes those born before effective treatment was developed, those born during the period of total care (1959-71) and those born during the period when

INDEX POPULATION	AUTHORS	TOPICS
(i) 168 unselected survivors born 1967-69	SPAIN (1969)	School population
	SPAIN (1970)	Spina Bifida Survey
	SPAIN (1972)	Verbal and performance ability
	SPAIN (1974)	Verbal and performance ability
(ii)168 unselected survivors born 1967-69	HALLIWELL ET AL (1980)	Intellectual and educational functioning
	CARR ET AL (1981)	Educational attainments
	CARR ET AL (1983)	Spina bifida survey
	CARR ET AL (1984)	School type and everyday life
	PEARSON ET AL (1985)	Self concept
	PEARSON ET AL (1988)	Handwriting
	CARR ET AL (1988)	Psychomotor performance

TABLE 52 : Major publications from the Greater London Survey according to age (i) birth to school age (ii) 11 and 12 years old.

selective surgery was practised (post 1971).

Although a core group of cases will be represented in most studies based in Sheffield, the method of case selection employed allows only those fitting the criteria under consideration to be selected. Numbers of cases vary therefore and age variations can be large. The majority of publications consider intellectual level and educational attainments eg. Lonton (1977, 1979) with particular interest being shown in the integration of SBH children into mainstream schools (Lonton, 1981; Lonton et al, 1986). The adolescent and young adult with SBH also receives particular attention (Lonton et al, 1983, 1984).

In addition, the Sheffield Study attempts to relate specific measurements to later physical and intellectual handicaps eg. lacunar skull deformity (Lonton et al, 1975), CT scans (Lonton, 1979). This possibly follows the Lorber tradition of a search for predictive measurable factors which could determine the course of treatment at birth. Table 53 lists the main areas of study.

INDEX POPULATION	AUTHORS	TOPIC
524 unselected cases	LORBER (1971)	Results of treatment
59 untreated cases	PARSONS (1972)	Aptitudes of school leavers
123 unselected cases	LONTON ET AL (1975)	Lacunar skull deformity and intelligence
203 unselected cases	LONTON (1976)	Hand preference
190 unselected cases	LONTON (1977)	Location of the lesion
467 selected and unselected cases	LONTON (1979)	CAT scans
1000 mixed group	LONTON AND SKLAYNE (1980)	Social class
132 cases, 57 unselected, 42 selected	SKLAYNE (1981)	Self concept and attainments

TABLE 53 : Main publications from the Sheffield Study (cond).

INDEX POPULATION	AUTHORS	TOPIC
1235 mixed group	LONTON (1981)	Integration
966 unselected cases	LONTON (1982)	Prediction of intelligence
115 unselected cases	LONTON ET AL (1983)	SB adults
38 selected cases	DODD (nee SKLAYNE)(1984)	Types of schools
157 unselected cases	LONTON ET AL (1984)	Employment
1367 unselected cases	LONTON (1985)	Gender
1000 unselected	LONTON ET AL (1986)	Integration

TABLE 53 : Main publications from the Sheffield Study.

APPENDIX III : THE WECHSLER SCALES

Whereas many IQ tests have only one measure, Wechsler developed his original test with the aim of providing separate assessments of verbal and non-verbal skill (Wechsler, 1939). The test, therefore, included 11 subtests, 6 verbal tasks (Verbal Scale) and 5 non-verbal tasks (Performance Scale). For all subtests, the raw scores are first converted to standard scores and then to three IQs (Full Scale, Verbal and Performance IQ) with a mean of 100 and a standard deviation of 15. According to Wechsler, the range of intellectual ability covered by the IQ scores produced is from mentally deficient to very superior.

Over the years, Wechsler has developed several different forms of this original Scale, but all constructed in the same way. The format of the three main Wechsler Scales in current use is given in Table 54. Revised versions of the WAIS and WISC have also been produced (Wechsler, 1974, 1981). These tests introduced some new items but retained the same basic format, as shown in Table 55.

TEST	AGE RANGE	TEST FORMAT
Wechsler Adult Intelligence Scale (WAIS)	16 yrs upwards	6 Verbal Tests 5 Non-verbal Tests
Wechsler Intelligence Scale for Children (WISC)	6-16 years	6 Verbal Tests 6 Non-verbal Tests
Wechler Pre-School and Primary Scale of Intelligence (WPPSI)	4-6 1/2 years	6 Verbal Tests 5 Non-verbal Tests

TABLE 54 : Format of the three main Wechsler Scales

	WAIS	WISC	WPPSI
VERBAL SUBTESTS	Information	Information	Information
	Comprehension	Comprehension	Comprehension
	Arithmetic	Arithmetic	Arithmetic
	Similarities	Similarities	Similarities
	Vocabulary	Vocabulary	Vocabulary
	Digit Span	Digit Span	
			Sentences
NON-VERBAL SUBTESTS	P.Completion	P.Completion	P.Completion
	Block Design	Block Design	Block Design
	P.Arrangement	P.Arrangement	
	Obj.Assembly	Obj.Assembly	
		Mazes	Mazes
	Digit Symbol		
		Coding	
			Animal House
			Geom.Design

TABLE 55 : Subtests of the Verbal and Nonverbal Scales of the Wechsler Adult Intelligence Scale (WAIS), Wechsler Intelligence Scale for Children (WISC) and the Wechsler Pre-school and Primary Scale of Intelligence (WPPSI).

APPENDIX IV : BANSTEAD MOBILITY CENTRE DRIVING ASSESSMENT

Driving Ability Assessment at Banstead Mobility Centre aims to provide a comprehensive assessment of the medical, visual and cognitive aspects of a person's disability, as related to driving, in addition to advice on physical ability and car adaptations. The five parts of the assessment are as follows:-

1. MEDICAL ASSESSMENT

(i) Medical history, including current medication.

(ii) Neurological examination.

(iii) Presence of "relevant" disability, ie. epilepsy, sudden attacks of faintness or dizziness without warning, vision below the legal standard and severe sub-normality (as outlined by the Department of Transport).

(iv) Presence of prospective disabilities in which defects exist but do not automatically prevent driving eg. stroke, hydrocephalus, head injury, multiple fractures, diabetes.

2. VISUAL ASSESSMENT

(i) Static visual acuity. (Snellens 6/10 in either eye, with or without glasses is required.)

(ii) Involuntary eye movements, squints and head postures.

(iii) Binocular vision and presence of double vision.

(iv) Colour perception (Ishihara Colour Test).

(v) Visual fields. (The field of vision required is 120 degrees across the horizontal, with 20 degrees above and below the horizontal.) This excludes all those with a complete homonymous hemianopia or marked quadrant field loss.

3. COGNITIVE ASSESSMENT

(i) Visual perceptual skills.

(ii) Spatial Orientation.

(iii) Learning and memory skills.

4. PHYSICAL ASSESSMENT

(i) Strength and range of movement of all limbs.

(ii) Co-ordination and proprioception.

(iii) Sitting height, stability and posture.

(iv) The implication of (i), (ii) and (iii) for car seating, use of car controls, secondary controls, car entry and exit.

(5) STATIC UNIT AND IN-CAR TESTS

(i) Number plate test : ability to read a number plate at 67 feet (3 1/8 inch high letters) or 75 feet (3 1/2 inch high letters).

(ii) Steering strength and brake poundage.

(iii) Simple and choice reaction time to lights and sound.

(iv) Track and road test (if applicable) in suitably adapted cars.

APPENDIX V : THE DRIVING PROGRAMME

1. RATIONALE FOR THE DRIVING PROGRAMME

In a recent overview of driver education generally, Brown et al (1987) carefully considered the contribution of driver training to road safety. These authors listed the aims of driver instruction as follows:-

(i) To provide drivers with the set of perceptual-motor skills which will enable them to control their vehicles.

(ii) To provide them with the set of rules, based on traffic law and conventional patterns of road user behaviour, which will enable them to interact safely with other traffic under normal conditions.

(iii) To provide them with relevant knowledge about the characteristics of traffic system components, which will enable them to exercise judgement, take decisions and use their control skills in novel situations where rule-based behaviour appears inappropriate or inadequate.

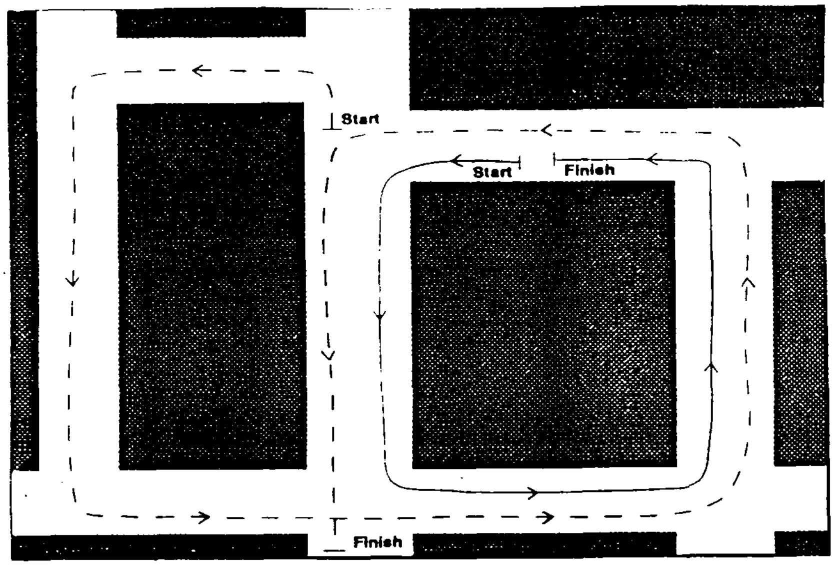
These three aims were considered by Brown and his colleagues to represent three stages of learning during the tuition period. They described these learning phases as skill based, rule based and knowledge based learning.

While it has already been noted that SBH learner drivers might have special problems, the general aims of driver education seem applicable for the development of a programme of structured tuition. As the focus of this programme for learner drivers with spina bifida and hydrocephalus was on the early tuition period (and was partly off-road driving) the learning considered was primarily skill and rule based, according to the definitions of Brown et al (1987).

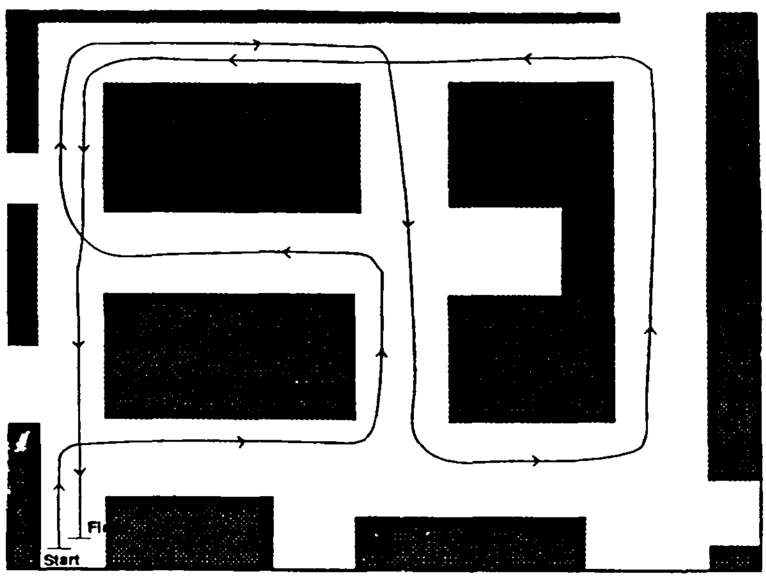
THE STRUCTURED TUITION PLAN

The structured tuition plan laid particular emphasis on the efficient use of car controls, the early lessons taking place in an off-road situation. Driving instructors were trained to use set methods to teach safety and road procedures, ensuring that each pupil was given consistent instructions and opportunity for practice. These procedures are described below.

For the initial training period on the road, simple and complex set routes were devised to allow progress from one lesson to another to be monitored. As shown in Figure 18, the simple route included left turns only, to avoid the



A Simple Route to Practise Left Hand Turns



A More Complex Route Using Left and Right Turns

FIGURE 18 : Simple and complex routes for structured tuition (from Simms and Nicholls, 1988).

necessity of crossing traffic. Once these procedures were learnt, progress was made to a more complex route, involving left and right turns, additional positioning and crossing the path of traffic.

2. SAFETY AND ROAD PROCEDURES (Automatic Car)

2.1. SAFETY PROCEDURES

PRE-DRIVING CHECK

(i) Security of wheels.

(ii) Tyres, pressures, tread depth and damage.

(iii) Oil, water, windscreen washer bottle and other fluid levels.

(iv) All lights.

(v) Windscreen wipers and washers.

(vi) Horn.

On the courses this procedure is demonstrated on the first lesson but thereafter a verbal check only is made.

COCKPIT DRILL

(i) Check handbrake on.

(ii) Check gear lever is in park.

(iii) Check doors are closed but unlocked.

(iv) Is the seating correct and comfortable?

(v) Fasten seatbelt.

(vi) Adjust mirrors.

2.2. ROAD PROCEDURES

STARTING DRILL

(i) Switch on ignition and check panel lights are on.

(ii) Select neutral.

(iii) Start engine.

(iv) Check panel light goes out.

(v) Check fuel guage and other instruments.

(vi) Apply hand operated brake (or foot brake) before gear selection.

MOVING OFF

(i) Select D.

(ii) Look in mirrors to ensure road is clear.

(iii) Signal if necessary.

(iv) Look in mirrors again and check blind spots over both shoulders.

(v) Release handbrake slowly and return hand to steering wheel.

(vi) Press accelerator gently to ensure smooth move off.

STOPPING

(i) Select safe place.

(ii) Look in mirrors and give signal in good time.

(iii) Slowly release accelerator and brake gently but progressively.

(iv) When stopped apply handbrake.

(v) Select neutral.

(vi) Remove hands from controls and switch off engine, if necessary.

EMERGENCY STOP

(i) Remove pressure from accelerator and apply brake quickly and firmly.

(ii) Tighten grip on steering, keeping the car in a straight line.

(iii) Ensure wheels do not lock.

(iv) When stopped apply parking brake.

(v) Select neutral.

(vi) Prepare to move off.

The emergency stop procedure is taught at an early stage to encourage the pupil to feel in full control of the car.

APPENDIX VI : RAW DATA

01	1	1	16	09	01	138	13	07	01	08	1
02	1	0	25	10	00	106	13	10	06	07	1
03	1	0	08	10	02	141	13	11	03	03	1
04	1	0	22	12	00	102	13	09	09	08	1
05	1	1	24	15	00	168	14	11	15	10	1
06	1	8	04	04	14	127	01	08	00	01	1
07	1	0	18	10	00	167	15	10	09	06	1
08	1	0	08	07	03	122	12	10	03	02	1
09	1	0	12	17	00	145	16	10	05	01	1
10	1	2	16	08	04	280	13	09	06	09	1
11	1	0	10	06	00	161	13	12	11	08	1
12	1	1	20	08	01	119	14	11	07	08	1
13	1	1	12	11	00	124	11	07	02	02	1
14	1	0	24	17	00	102	11	11	17	10	1
15	1	0	14	12	04	136	16	15	07	07	1
16	1	1	24	17	01	144	16	10	10	11	1
41	2	0	22	07	00	148	15	09	06	06	1
42	2	1	12	12	00	130	14	06	10	09	1
43	2	0	16	13	01	097	16	13	07	09	1
44	2	0	14	06	02	181	16	09	03	06	1
45	2	0	20	09	01	150	15	09	03	07	1
46	2	0	12	08	03	173	08	10	04	03	1
47	2	0	16	11	00	147	11	09	13	10	1
48	2	0	08	04	03	158	10	09	05	02	1
49	2	1	06	10	01	135	13	09	02	06	1
50	2	1	18	13	00	126	15	10	03	06	1
51	2	0	20	07	01	128	15	10	05	07	1
52	2	1	16	12	00	114	15	14	09	09	1
53	2	4	10	07	01	141	12	09	05	03	1
54	2	0	16	11	00	14.	13	12	07	13	1
55	2	0	27	11	01	101	16	10	07	12	1

TABLE 56 : Raw scores of SBH subjects on 8 tests.

Column key to data list : subject ID 1-4, Token Test 6, Picture Arrangement 8-9, Picture Completion 11-12, Letter Cancellation Errors 14-15, Letter Cancellation Time 17-19, Road Map Test 21-22, Digit Span 24-25, Logical Memory 27-28, Visual Reproduction 30-31, Battery 33.

17	1	1	18	09	08	180	13	11	07	02	01	6	6
18	1	0	16	09	01	120	16	12	11	06	02	6	4
19	1	0	12	08	04	172	15	06	02	09	08	3	5
20	1	0	16	08	03	140	12	06	04	04	04	2	3
21	1	0	18	08	00	140	13	10	08	05	06	7	6
22	1	0	22	07	01	078	08	12	10	09	05	6	5
23	1	1	16	09	00	208	16	10	07	08	02	6	4
24	1	0	16	09	00	140	11	08	09	03	03	6	5
25	1	0	22	13	00	130	16	10	05	09	07	6	4
26	1	0	20	15	00	120	15	13	07	08	04	5	6
27	1	2	14	12	00	161	15	12	06	09	04	6	5
28	1	0	16	08	00	113	11	11	11	06	01	4	4
29	1	0	10	06	04	140	14	11	06	06	08	0	3
30	1	0	26	13	00	095	15	10	06	10	16	4	6
31	1	0	22	15	00	146	16	15	10	10	06	6	4
32	1	0	04	14	06	140	10	09	05	06	05	2	6
33	1	0	12	15	01	122	14	09	07	06	04	7	6
34	1	2	06	14	00	105	16	10	12	03	02	3	6
35	1	0	04	06	01	186	11	10	00	02	03	1	5
36	1	0	14	14	02	140	08	09	12	09	05	4	2
37	1	1	12	08	00	117	14	10	04	04	02	4	5
38	1	0	14	07	02	140	15	08	07	08	16	6	6
39	1	0	18	13	00	137	12	11	07	07	07	5	6
40	2	0	16	11	00	144	13	12	07	09	13	1	6
56	2	0	12	08	00	174	10	16	04	06	11	2	4
57	2	0	12	06	01	141	15	15	04	02	02	4	2
58	2	1	14	09	01	129	16	11	13	08	04	2	5
59	2	4	10	05	09	168	10	08	01	02	00	0	0
60	2	0	22	14	00	109	15	09	07	06	02	4	6
61	2	1	18	12	01	147	16	08	04	06	00	6	6
62	2	0	22	11	01	123	15	12	11	07	09	6	6
63	2	1	14	07	04	128	10	08	03	03	02	5	4
64	2	1	20	09	05	122	14	07	05	11	05	6	0
65	2	1	12	05	02	129	10	07	03	04	01	3	2
66	2	1	12	04	05	141	09	10	06	02	01	3	1
67	2	2	14	16	00	176	16	14	10	07	03	4	6
68	2	0	10	09	00	217	13	10	06	05	02	2	3
69	2	0	20	07	00	121	16	11	10	11	16	6	6
70	2	0	16	11	00	144	13	12	07	09	13	1	6

TABLE 57 : Raw scores of SBH subjects on 11 tests. Column key to data list: Columns 1-31 as shown in Table 56, Pattern Copying 33-34, Line Tracing 36, Embedded Figures Test 38.

01 0 13 18 10 06 13 00 126 04 6 04 15	01 0 14 18 14 07 09 04 083 05 6 07 11
02 1 12 23 14 12 12 00 069 16 6 10 10	02 1 10 24 12 07 07 00 105 08 6 05 13
03 0 12 24 10 04 08 00 079 08 6 05 12	03 0 12 22 11 06 03 00 085 06 5 05 15
04 1 13 28 09 10 09 02 096 10 6 07 13	04 0 06 10 11 08 08 00 125 13 6 07 14
05 1 07 06 07 04 07 01 100 05 6 02 11	05 0 15 31 09 09 06 00 100 08 6 06 13
06 1 10 20 11 07 08 00 077 05 6 06 10	06 0 06 06 08 04 06 00 117 03 3 06 14
07 1 09 28 08 07 07 00 095 06 6 08 11	07 0 17 26 13 13 11 00 088 04 6 07 16
08 1 17 30 09 09 14 00 070 16 6 09 13	08 1 11 12 07 02 02 00 124 ** * ** 11
09 1 19 28 13 07 12 00 101 16 6 08 16	09 2 11 10 07 07 01 01 141 ** * ** 15
10 2 07 22 09 05 02 07 141 14 6 07 16	10 0 12 14 15 07 07 04 136 ** * ** 16
11 1 09 14 09 10 11 04 084 06 6 06 09	11 0 15 27 09 13 13 01 078 05 6 06 14
12 0 05 18 10 12 06 01 123 07 6 06 14	12 0 ** 26 11 ** 09 00 110 13 6 ** 16
13 1 16 31 12 07 12 00 110 10 6 06 13	13 0 14 14 09 12 09 02 *** 05 2 04 08
14 0 16 25 08 01 06 03 104 10 6 05 14	14 1 13 26 11 06 06 00 095 16 6 04 15
15 1 12 22 13 08 05 00 096 06 6 09 11	15 0 14 26 12 15 08 00 105 08 6 03 16
16 1 10 22 09 10 10 02 095 05 6 07 06	16 0 17 32 09 13 13 01 087 14 6 08 15
17 0 08 14 11 02 03 01 138 11 6 04 09	17 0 08 20 11 07 08 01 119 ** * ** 14
18 0 12 22 11 06 09 00 085 16 6 06 16	18 0 06 10 11 08 07 01 092 04 6 04 13
19 1 15 26 10 14 11 01 115 13 6 06 15	19 1 11 24 09 10 10 00 101 04 6 07 16
(a) Raw Scores for able-bodied group	(b)Raw scores for SB only group

TABLE 58 : Raw scores of 4 matched groups

(a) able-bodied Ss (b) spina bifida only Ss

* missing data. Column key to datalist :

Subject ID 1-2, Token Test 4, Picture

Completion 6-7, Picture Arrangement 9-10,

Digit Span 12-13, Logical Memory 15-16 (cond).

01 0 17 18 12 11 11 00 086 11 6 06 16	01 0 08 04 10 07 02 02 391 00 3 01 07
02 * 08 12 10 04 04 00 117 02 5 04 14	02 2 03 08 08 01 01 27 140 04 5 05 11
03 0 08 16 11 11 06 00 113 01 4 04 11	03 2 13 18 11 13 10 02 084 05 6 08 12
04 0 07 22 12 10 09 01 078 05 5 06 08	04 2 ** 10 ** ** 05 00 116 03 6 01 08
05 1 06 04 08 02 03 01 158 01 3 03 06	05 0 08 20 07 10 08 00 099 14 5 05 09
06 2 14 06 10 12 03 00 105 02 6 03 16	06 1 07 10 09 00 05 02 182 09 5 06 14
07 0 11 06 11 08 06 00 200 09 6 04 15	07 1 04 10 07 02 04 24 177 00 2 01 09
08 0 07 20 11 10 11 00 121 16 6 06 16	08 1 12 04 09 08 05 00 279 03 6 03 08
09 0 08 12 06 02 09 04 172 08 5 03 15	09 0 04 04 07 03 08 02 213 02 5 00 10
10 1 14 22 09 06 06 01 217 05 6 04 16	10 0 08 08 09 09 02 00 170 08 6 05 15
11 1 11 14 08 03 05 01 093 05 6 06 12	10 0 14 12 08 10 05 00 124 11 5 07 16
12 2 12 14 12 06 09 00 161 04 5 06 15	11 0 15 30 11 14 12 02 125 07 6 04 16
13 1 06 16 13 11 06 00 098 01 4 02 08	13 1 ** 16 ** 08 03 00 122 00 3 02 09
14 1 09 18 11 07 02 08 180 01 6 04 13	13 2 ** 02 09 ** 02 01 100 07 6 06 09
15 0 15 14 13 11 10 00 180 11 6 06 14	15 4 04 06 05 02 01 03 231 01 4 00 06
16 0 11 14 09 02 06 00 146 00 4 05 08	16 0 ** ** ** ** 10 00 172 02 5 02 15
17 0 14 20 10 12 10 02 108 06 6 05 12	17 * 14 22 11 07 08 01 133 ** * ** 14
18 0 08 14 09 ** 10 02 168 05 6 05 10	18 0 12 ** 12 10 ** ** *** ** 5 03 16
19 1 17 22 09 11 08 01 181 02 6 03 15	19 1 09 04 11 06 08 02 312 05 6 02 15
(c)Raw scores for SBH group	(d)Raw scores for CP group

TABLE 58 : Raw scores of 4 matched groups

(c) SBH subjects (d) CP subjects. Column key cond. Visual Reproduction 18-19, Letter Cancellation Errors 21-22, Letter cancellation Time 24-26, Pattern Copying 28-29, Embedded Figures Test 31, Line Tracing 33-34, Road Map Test 36-37.

0111110016110144161061120793415083135232141280
0221200118130184140365080252610057223002601340
0312111216084280100834090692814238187002429291
0421201012052129020123070342109037118902468250
0522110004061186110351100021604110137443008240
0612111012063177150234150422820067097013470230
0711210122171181150263091183719087077001300311
0812111122182123140753100552517269120032730421
0912111014130104161264150663820190097001800431
1011101012111199160163100463614078080052030160
1111200026161107151667131193819068090011519341
1212111114070147110564090683415231087502040301
1322110108111140160564080493318074153151766230
1421111004071117050023080022114048099802141360

TABLE 59 : Raw scores for 14 learner drivers

Column key for datalist : Subject ID 1-7, Token Test 8, Picture Arrangement 9-10, Picture Completion 11-12, Letter Cancellation Error 13, Letter Cancellation Time 14-16, Road Map Test 17-18, Pattern Copying 19-20, Embedded Figures Test 21, Line Tracing 22, Digit Span 23-24, Logical Memory 25-26, Visual Reproduction 27, EOT 28-29, RFT 30-31, ETST 32-34, Straight Tracking 35-38, Cones displaced 39, Figure 8 40-43, Driving Checklist 44-45, Driving Status 46.

06 5 14 15 16 3 2 0 2 04

07 5 18 12 17 6 6 1 1 12

08 5 18 14 13 5 4 0 0 09

09 6 16 10 17 4 6 0 1 10

10 8 16 10 17 5 4 3 3 09

11 5 18 18 16 6 6 0 0 10

12 7 17 16 12 6 3 1 0 08

13 6 17 13 15 6 6 0 0 12

14 7 12 10 13 6 6 0 0 06

TABLE 60 : Raw scores for 9 learner drivers on driving related learning tests. Column key for datalist: Subject ID 1-2, Trials to learn road signs 4, Signs recalled 6-7, Signs recognised at 6 days 9-10, Signs recalled at 6 days 12-13, Landmark recall 15, Landmark recall at 6 days 17, Route errors 19, Route errors at 6 days 21, Map Drawing 23-24.

APPENDIX VII : PUBLICATIONS

SIMMS, B. (1986) Learner drivers with spina bifida and hydrocephalus: the relationship between perceptual-cognitive deficit and driving performance. Zeitschrift fur Kinderchirurgie, 41, Supplement I, 51-55.

SIMMS, B. (1987) The route learning ability of young people with spina bifida and hydrocephalus and their able-bodied peers. Zeitschrift fur Kinderchirurgie, 42, Supplement I, 53-56.

SIMMS, B. (1987) A 3-year follow-up of the driving status of 32 young adults with spina bifida. International Disability Studies 9, 177-180.

SIMMS, B. (1989) Driver education: the needs of the learner driver with spina bifida and hydrocephalus. Zeitschrift fur Kinderchirurgie, 44, Supplement I, 35-37.

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SIMMS, B. (1987) The brain-damaged learner driver: screening. Medicine and Law, 6, 159-64.

SIMMS, B. and NICHOLLS, W. (1988) The Learner Driver with Spina Bifida and Hydrocephalus. Notes for Driving Instructors. London. ASBAH.

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Simms, B. (1986). Learner drivers with spina bifida and hydrocephalus: the relationship between perceptual-cognitive deficit and driving performance. *Zeitschrift fur Kinderchirurgie: organ der Deutschen, der Schweizerischen und der Osterreichischen Gesellschaft fur Kinderchirurgie= Surgery in infancy and childhood, 41*, 51-55.

Simms, B. (1987). The route learning ability of young people with spina bifida and hydrocephalus and their able-bodied peers. *Zeitschrift fur Kinderchirurgie: organ der Deutschen, der Schweizerischen und der Osterreichischen Gesellschaft fur Kinderchirurgie= Surgery in infancy and childhood, 42*, 53-56.

Simms, B. (1987). A 3-year follow-up of the driving status of 32 young adults with spina bifida. *Disability & Rehabilitation, 9*(4), 177-180.

Simms, B. (1989). Driver education: The needs of the learner driver with spina bifida and hydrocephalus. *Z Kinderchir, 44*(suppl 1), 35-37.