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IDENTIFICATION AND INVESTIGATION OF DYSCALCULIA

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ABSTRACT

Dyscalculia is defined as a structural disorder of mathematical abilities, leading to underachievement in Mathematics, and having its origin in a genetic or congenital disorder of those parts of the brain that are the direct anatomico-physiological substrate of mathematical abilities, without an obvious simultaneous disorder of general mental functions.

A search of the literature yielded enough evidence for its existence to justify an investigation, especially bearing in mind the educational implications of the existence of dyscalculic children.

The investigation was conducted using two complementary procedures: computer-aided analysis of data from a national sample of over 14,000 children, and case studies of individual children in local schools, using a battery of psychological tests. Each procedure started with the identification of a group of children who were underachieving in Mathematics relative to their peers.

Mathematical underachievement was associated in the case study group with three significant areas of functioning: certain anomalous laterality preferences, poor short-term memory, and large Verbal-Nonverbal ability differences. The first of these areas was also indicated in the analysis of the national sample, where it occurred in conjection with poor coordination and abnormal pregnancy or birth data.

Studies of each of the three 'significant areas' revealed strong links with neurological disorders described in the literature. There were indications that each area was also linked with underachievement in Mathematics.

It was found that the psychological tests which identified the three 'significant areas' of functioning were of use in identifying a mathematical underachiever in a 'normal' class.

Although this investigation cannot claim to be conclusive, it adds to the construct validity of the concept of dyscalculia and points to aspects of mathematical underachievement which need further investigation.

ABBREVIATIONS USED IN THIS THESIS

The following abbreviations are sometimes used without explanation in the text.

NCDS - National Child Development Study.
PMS - Perinatal Mortality Survey.
NFER - National Foundation for Educational Research.

BAS - Bristol Ability Scales.
BSAG - Bristol Social Adjustment Guides.
WAIS - Wechsler Adult Intelligence Scales.
WISC - " Intelligence Scales for Children.
WISC-R - " " " " " (Revised version).

PIQ - Performance subscales score on a Wechsler Intelligence Scale.
VIQ - Verbal ability " " " " " Intelligence Scale.
FSIQ - Full scale score on a Wechsler Intelligence Scale.

T - Total NCDS Population.
V - Verbal.
NV - Nonverbal.
M - Mathematics.
RC - Reading Comprehension.

TA = Total ability score on the NCDS general ability test.
VA = Verbal ability score on the NCDS general ability test.
NVA = Nonverbal ability score on the NCDS general ability test.

MQ = Medical Questionnaire. PQ = Parental Questionnaire.

LD = Learning Disabled. RD = Reading disabled.

R = Right. H = Hand. R-H = Right hand(ed). etc.
L = Left. F = Foot. L-H = Left hand(ed).
M = Mixed. E = Eye. M-H = Mixed hand(ed).

STM - Short-term memory. LTM - Long term memory. MS - Memory Span.

Subgroups identified in the NCDS data:

MA = Middle ability: children whose total ability scores fell between the 30th and 60th centiles.
MU = Mathematical underachiever: a child scoring more than 2 s.e.s. below expectation on the Maths. test.
RU = Reading underachiever: a child scoring more than 2 s.e.s. below expectation on the R.C. test.
SMU = Specific mathematical underachiever: A MU who also scored less than 1 s.e. below expectation on the RC test.
SMU* = SMU + either M score 3 s.e.'s. below expectation, or RC score 2 s.e.'s above expectation.

SRU = Specific Reading underachiever: A RU who also scored less than 1 s.e. below expectation on the M test.
SRU* = SRU + RC score 3 s.e.'s below expectation.
TM = Top Maths.: Children who scored 39 or 40 on the M test.
E-Group = Children with very large (60 centiles) discrepancies between VA and NVA scores on the general ability test.
OBD = No birth data: Children with no birth (PMS) data.
OTA = No total ability: Children with no TA record at age 11.

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CHAPTER I

BACKGROUND OF THE CONCEPT OF DYSCALCULIA AND RATIONALE OF OUR INVESTIGATION

We begin by deriving a definition of developmental* dyscalculia in the sense in which it will be used throughout this thesis. This will be followed by a discussion of the concept and the case for retention of a specific name for the disorder.

Evidence is suggested for believing that dyscalculia may exist as a practical proposition and not simply as a concept, but the difficulties of 'proof' of its existence are acknowledged in relation to the purpose of the study.

Finally, two complementary but contrasting procedures for investigating the concept are outlined : statistical analysis of data from a national study, and individual case studies in local schools.

THE CONCEPT OF DYSCALCULIA

The term 'dyscalculia' has been appearing in the literature for about 60 years, at first associated with neurological work, particularly brain damage (e.g. Gerstmann [1], Cohn [2]) but more recently associated with educational research, where it has been identified in terms of Mathematical achievement or under-achievement (e.g. Kosc [3], Flinter [4], Weinstein [5]). Nowadays it may be used in two different senses : developmental dyscalculia being failure to acquire Mathematical concepts or expertise, and acquired dyscalculia being the loss of these Mathematical abilities after they have been acquired, usually due to brain damage. This situation is exactly parallel to

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* 'Developmental' will be assumed throughout this thesis wherever dyscalculia is used, except where the adjective 'acquired' is specifically stated or where inverted commas are used.

the notions of developmental and acquired dyslexia.

There is no difficulty with the definition or existence of acquired dyscalculia or its cause (e.g. Luria [6], Critchley [7]), but the situation is very different for developmental dyscalculia. So far, there is a confusion of terms and definitions, and a lack of concensus on prevalence and causes. It has been defined with various degrees of precision, particularly as regards its actiology, from Flinter's [4] :

> "disturbances in arithmetic that result from disorders of quantitative thinking are referred to as forms of dyscalculia"

to Kosc's [3] :

> "developmental dyscalculia is a structural disorder of mathematical abilities which has its origin in a genetic or congenital disorder of those parts of the brain that are the direct anatomico-physiological substrate of the maturation of the mathematical abilities adequate to age without a simultaneous disorder of general mental function".

Thus, Flinter confined his definition to one specific area of Mathematics, namely arithmetic, and did not specify a cause or distinguish between developmental and acquired disorders, or require a minimum general ability. On the other hand, Kosc, who regarded Mathematical abilities as specific abilities which are relatively isolated, allowed that dyscalculia could result in impairment of certain Mathematical functions while others remain intact. He further specified that the cause is a disorder of some part or parts of the brain, that this disorder is genetic or congenital, and that general mental functioning is normal.

We feel that definitions of the former type (Flinter) are too narrow, in the sense of including only one aspect of Mathematics, and too wide, in the sense of including a wide variety of causes, from poor teaching, to mental deficiency, or acquired brain damage. Such definitions concentrate on defining specific symptoms rather than the nature of underlying causes. The latter will also be the point of our disagreement with those who advocate the terms "specific mathematics retardation" and "specific reading retardation" (e.g. Lansdown [8], Rutter and Yule [9], the Bullock Committee Report [10]) to cover the disorders of dyscalculia and dyslexia.

On the other hand, Kosc's definition results in a range of symptoms (which can, however, be translated into a single educational variable in terms of under-achievement in Mathematics) which arise from a range of specific causes (which can be translated into a single broad causal variable as a genetic or congenital disorder of some part or parts of the brain). The major drawback of this approach, as its critics have emphasised, is that "a genetic or congenital disorder of some part or parts of the brain" may not be amenable to clear diagnosis (except in cases of acknowledged brain damage*, in which case the disorder is likely to extend to other academic areas). However, neurological psychology is a relatively new science, and it is not inconceivable that such diagnosis will become possible in the

* We shall exclude from our investigation and future discussion, children who have been unequivocally diagnosed as "brain damaged".

the not-too-distant future. Moreover, this objection really relates to how the concept is operationalised and not to the concept *per se*.

We favour Kosc's approach to the definition of the concept of dyscalculia. However, Kosc's definition contains an ambiguity : he requires Mathematical abilities to be less than "adequate to age" only, whereas he requires no disorder of general mental functions. Indeed, in [3] he goes on to define potential dyscalculics by the Mathematics Quotient :

$$MQ = \frac{\text{Maths. Age}}{\text{Chronological Age}} \times 100$$

less than 70 to 75, thus ignoring differences in general mental functioning within a peer group. This would imply that a child of very superior mental ability whose Mathematical performance was average for his age could not be dyscalculic, whereas a child of very inferior mental ability whose Mathematical performance was average for his mental ability would almost certainly be classified as dyscalculic.

We shall adopt a modification of Kosc's definition with the interpretion that mental age as well as chronological age is taken into account in assessing the disorder of Mathematical abilities, that is, we shall require serious <u>under-achievement</u> in Mathematics. In addition, we will attempt to avoid a possible ambiguity in Kosc's definition which arises from the degree of specificity of disturbance required. Bearing in mind some of the recent research into brain functioning which, as Luria [11] comments, sees the brain less as a collection of discrete specific functions localised to specific sites and more as active connections between more general basic localised functions, some of "those parts of the brain that are the direct anatomico-physiological substrate of mathematical abilities" may be involved in types of performance other than strictly mathematical, or in more than one area of mathematics. That is, "mathematical abilities" may also include some abilities which while vital to mathematical performance may also affect other areas, though less acutely. However, a disorder of such a part of the brain would, in this modified view, still lead to a disturbance fairly specific to mathematics and severe under-achievement in Mathematics relative to general mental ability.

The following definition of dyscalculia will therefore be used as a basis for this thesis.

Definition : (Developmental) dyscalculia is a structural disorder of mathematical abilities, leading to underachievement in Mathematics, and having its origins in a genetic or congenital disorder of those parts of the brain that are the direct anatomico-physiological substrate of mathematical abilities, without an obvious disorder of general mental functions.

More loosely, this can be expressed as under-achievement in Mathematics due to genetic or congenital neurological impairment.

We note that our definition allows for both a structural disorder which is permanent (i.e. due to malformation or damage during formation, of some structure) and a structural disorder which is temporary (i.e. a lag in maturation). We do not differentiate between these two possibilities at this stage, since both imply that normal use of the disordered structure is impossible. However, there are distinctions between them; the first implies that a normal pattern of mathematical development may be impossible for those areas of Mathematics which utilise the malformed or damaged structure, whereas the second implies a normal, but delayed, development. The first possibility also implies that some areas of Mathematics may always be difficult, unless strategies which by-pass the malformed structure can be found, whereas the second possibility implies that with maturation, normal learning will eventually be possible (unless there is a 'critical period' for learning behaviour).

These same possibilities arise in dyslexia, where some researchers take the view, as we do, that both arise from 'neurological' causes and both require the same remediation if learning is to take place immediately (e.g. Crosby [12]). Critchley [7] takes the opposite view, regarding the first possibility as 'brain damage', for which there is already adequate allowance in the educational system; moreover, the prognosis will be better for the 'late maturation' subjects (unless there is a critical period for learning). But this argument only holds if the 'brain damage' is actually diagnosed, and if the late maturers are motivated to catch up when maturation eventually takes place (assuming there is no 'critical period' for learning).

Nevertheless, there may eventually be some point in distinguishing between these cases, especially if it turns out that there is no critical period and if 'mature learning' becomes commonplace.

RELEVANCE OF THE CONCEPT OF DYSCALCULIA

It follows from our definition that dyscalculia is not a unitary concept; that is, it can manifest itself in a plurality of specific symptoms (although one general condition - under-achievement in Mathematics - will be present) and will also have a plurality of specific causes (although one general cause - neurological impairment - will exist). This being so, is there any justification for retaining the term "dyscalculia"? In spite of the criticisms, which will be discussed later, we think that there are three important reasons for doing so, assuming that it actually exists.

Firstly to draw attention to those children who may be suffering from some form of neurological deficit, yet who may have to endure lables such as "lazy" or "careless", when in fact they may be neither lazy nor careless, nor lacking in general ability. For such children, a recognition that they are failing in Mathematics despite adequate effort and attention could alleviate some of the emotional stress which undeserved derogatory lables produce.

However, we should make it very clear that we are not advocating the replacement of some (derogatory) labels by a more acceptable label, as some opponents of the concepts of dyslexia and dyscalculia seem to suggest, to be seized on by parents as an excuse for lack of intelligence or effort and by teachers as a signal for no further action. The term "dyscalculia" should be used in connection with a particular child only when :

(a) there is acceptable evidence for the existence of dyscalculia as an actual phenomenon;

(b) the child has been shown to be underachieving in Mathematics;

(c) there is some evidence that neurological functioning may not be entirely normal.

The diagnosis of dyscalculia should then signal both an acknowledgement of the child's general ability and potential for better Mathematical performance, and also the need for specialist help.

Our second reason for the retention of the term dyscalculia, should it exist, is to draw attention to the nature of dyscalculia : that is, its neurological origins. This would emphasise the distinction between mathematical underachievement caused by poor teaching, primary emotional disorders, adverse attitudes, lack of effort and poor motivation, and mathematical underachievement due to neurological disorders.

Opponents of dyscalculia argue that separating out these various causes is impossible and that more than one set of factors may be contributing to the mathematical underachievement. We would agree with Lansdown [8] that it would be remarkable if the frustration of underachievement, possible unfair labelling as "lazy", and perhaps parental disappointment, did not affect the child emotionally and behaviourally. Nevertheless, these effects would then be secondary to the primary dyscalculia. We do agree that at the present time a conclusive distinction between all the possible causes is not possible; but if neurological causes were considered in every case of mathematical underachievement and a neurological examination conducted, perhaps positive signs would be found in some cases even now (providing corroborative evidence for the concept). As Crosby [12] has pointed out, the need for neurological evaluation is rarely considered, so it is no wonder that neurological implications are rarely diagnosed. Moreover, with advances in technology, new techniques are becoming available, and advances in neurology and neuropsychology are also leading to significant advances in the diagnosis of neurological abnormalities. It is relevant to quote the findings of Johns *et al* [13] that arithmetic-disabled children could be distinguished from language-disabled and normal children on the basis of electrical recordings from various parts of the brain.

Thirdly, to draw attention to the need for special remediation or compensatory strategies to minimize the effects of the neurological disorder. This assumes that some conventional remediation techniques, usually based on the needs of slow learners, will not be totally adequate for dyscalculics, assuming that they do exist. These children would not be deficient in general intelligence, but only in some factor which contributes to mathematical performance. In order to make the best and fullest use of their general intelligence, these children would need a strategy to help them bypass the deficient factor now, even though this factor may develop automatically at some later time (developmental lag) in some of them.

Justification for research into the concept of dyscalculia has been discussed in this country fairly recently by Richards [14] and Blane [15]. Their discussions included justification in terms of educational policy. They felt that there was enough evidence to warrant further research, though they differed in the amount of weight given to the concept for practical purposes up to that time. Our research is an attempt to decide whether further weight can be given to the validity of the concept.

Our arguments for the retention of the term dyscalculia are similar to those which could be advanced in favour of retaining the term dyslexia, which is a similar multi-factional disorder affecting language abilities (particularly reading and spelling) (e.g. Miles [16], Critchley [7], Crosby [12]). In the large volume of literature devoted to dyslexia, the importance of the three reasons given above is frequently demonstrated : sufferers have described the relief at having their condition recognised and their simultaneous release from feelings of guilt and frustration in not being able to read; much research into the condition has followed the recognition of its neurological origins; and informed remediation measures, based on the neurological nature of the condition, have helped dyslexics to learn to read.

METHODOLOGICAL DIFFICULTIES IN INVESTIGATING THE CONCEPT

In order to prove conclusively that dyscalculia exists, it would be necessary to show, in some case of mathematical underachievement : (a) that there was a neurological impairment; (b) that the underachievement was caused by this impairment rather than by poor teaching, emotional disorders, or adverse social or motivational factors; (c) exactly how the particular impairment affected mathematical abilities and the exact mechanisms leading to the mathematical underachievement.

But neurological science is not sufficiently advanced as yet for us to say with certainty that in a randomly chosen child there is, or is not, a neurological impairment. Even a gross neurological impairment such as hemispherectomy, if performed very early in life, may in some cases only be detected by a trained neurologist using sophisticated procedures and specialised tests.

Behavioural sciences are also at a relatively early stage of development, which makes the ruling out of social, educational, emotional and motivational factors as prime causes of mathematical underachievement somewhat uncertain. The issue is further clouded by the probability (already noted, p. 9) that dyscalculia would lead to some emotional disturbance (particularly when the child has been given no credit for trying, or ridiculed for his lack of achievement), and that there may be pre-disposing social factors to the birth of a dyscalculic child, as there are to perinatal mortality [17].

Finally, knowledge of the brain mechanisms responsible for higher mental functions and specialised abilities is in its infancy. In few cases is there any known link between neurological impairment and mental functioning; where such links are known (e.g. some types of aphasia) the exact mechanisms cannot be specified. Indeed, given that a lesion in a specific brain site leads to loss of a particular aspect of language, it is still not possible to say with certainty if this is because the site is the seat of that aspect of language, or of a contributory vital factory to that aspect of language, or merely a link between such contributory vital factors.

However, this is not to say that because neurological and behavioural sciences are not sufficiently advanced as yet to make precise diagnosis, we should not attempt to investigate the area. What can be done is to investigate the construct validity of the concept of dyscalculia, and to build up this construct validity by evidence from numerous sources, with a view to deciding whether the principles and justification for labelling the disorder are really borne out.

Even without absolutely certain diagnosis, the finding of certain critical factors indicative of dyscalculia, would be welcome. The example of the many dyslexic children now receiving and benefiting (educationally and emotionally) from specialised help (e.g. Miles [16], Critchley [18], Naidoo [19]) is a good argument that similar help should be available now for suspected dyscalculic children. Moreover, this help, like that for dyslexics, should be based on neurological principles.

Our triple aims in this research are therefore to build up the construct validity of dyscalculia, by looking for neurological links with cases of mathematical underachievement; to look for ways in which the detection of dyscalculia might be operationalised now (i.e. some progress in the direction of a diagnostic instrument); and to look fcr pointers towards effective remediation. We hope to justify our investigation by making positive progress towards these aims.

Before we consider the basis for our optimism that these aims may have positive outcomes, by considering evidence from the literature to support the concept, we make a point about the interpretation of research findings.

A NOTE ON THE INTERPRETATION OF THE LITERATURE

One rather obvious point needs to be made, namely that the experiences, theories and beliefs of an author will affect the research that he reports. This will be true of the subject investigated, the methodology used, and the interpretation of findings. It will almost always entail unstated assumptions, which may be relevant to the interpretation of results, and to how far such results can be generalised.

For example, Krutetskii's experiences in his search for specific mathematical abilities, led him to state that :

> "absolute inability to study Mathematics, a kind of mathematical blindness, does not exist". (Krutetskii [20]).

Buxton's theory, that inability to do Mathematics is caused by fear of failure leading to panic, led him to attempt remediation by allaying fear of failure, and he then attributed the progress of his subjects to this remediation and confirmed his theory. But an alternative explanation is that these subjects suffered a "developmental lag" which had now disappeared (Buxton [21]).

Of course, our own investigation will also be affected by such factors; we are open to the possibility that dyscalculia may be a valid concept and may explain some cases of mathematical underachievement, and is consequently worthy of investigation. We believe that ability and achievement are different and that we can arrive at reasonably useful measures of both; we believe that ability can change as maturation and development occur, but that measures of ability will become increasingly stable with age; we believe that a number of factors can affect achievement - social, emotional, educational, motivational and neurological - and that in a random sample of underachievers we may find any or all of these factors.

Our methodology will utilise the idea that if a small group, A, of a population is affected by some factor, that factor will become more and more prominent as we select smaller and smaller subgroups of the population, each containing A. However, because we believe that the application of sophisticated statistical methods to unsophisticated raw data can lead to misleading results, only relatively simple statistics will be used. Paradoxically, in some instances this leads to more complex use of the computer and organisation of data. Our use of two complementary approaches, via large-scale computerised data and personal individual studies, also allows a wide overall view of generalities and details.

Finally, in interpreting and justifying our conclusions we attempt to acknowledge other possible interpretations, and give reasons to justify the balance of judgement arrived at.

We now turn to a consideration of the literature.

THE LITERATURE

For many reasons, not least the sparseness of literature specifically dealing with dyscalculia (however defined), we have also examined the literature on learning difficulties in Mathematics, learning difficulties in general, and dyslexia, as well as some of the literature on neurological impairment and neurological theories.

It is clear that relevant information might be found in any of these areas; dyscalculics as we have defined them could be included in any of the first three categories, while dyslexics have in some cases been defined analogously to our definition of dyscalculics with the substitution of "Language" for "Mathematics" wherever the latter occurs in our definition. The literature on neurological impairment could yield interesting comparisons between Mathematical difficulties following acquired diagnosed neurological impairment and general difficulties of mathematical underachievers. Finally, neurological theories have to be considered if credence is to be given to a neurological concept of dyscalculia.

THE SPARSITY OF DYSCALCULIA STUDIES

The small number of studies dealing with difficulties in Mathematics, compared with the vast volume of literature dealing with Language, and particularly with Reading, is mentioned by several authors (e.g. Critchley [7], Crosby [12], Weinstein [5]). The views usually expressed on why this should be so are (i) that reading is the key to both normal functioning in the adult world and to further learning, and so is much more important, especially in view of limited remedial resources, (ii) that girls are more often the ones who find Mathematics difficult, and numeracy is less vital to a woman than to a man, (iii) that many teachers are not only non-specialist teachers of Mathematics (especially at infant and junior levels) but even have difficulties themselves, and so cases of mathematical underachievement go undiagnosed, (iv) that Mathematics is often formally taught at a much later stage than Reading, and consists of many different types of concepts and processes, so that a child might be quite old before specific difficulties are noticed, by which time it might be thought too late for remediation. Some of this is expressed by Crosby [12] :

> "Standing alone as a disorder, dyscalculia is so seldom seen by neurologists that it is believed the disorder is rare. We are not certain this is the case. Gross difficulty in adding, subtracting, multiplying, dividing and in performing the higher forms of Mathematics can be neurological in origin, as well as caused by poor teaching techniques, lack of pupil interest and below average intelligence. It is certain that many students are less than brilliant in arithmetic for one reason or another.

"We suspect that a pure dyscalculia could be diagnosed by the nature of a child's mistakes. He would fail to grasp the principle behind the calculation. He would not be close in his answers, and he obviously would be guessing. The whole character of his calculation would differ from the child who was simply inexpert in his number facts.

"We have never seen a pure dyscalculia. It may be rare but we suspect the child who is poor in arithmetic is simply less of an educational problem. He fails that subject but if he reads and does well in other courses, he passes to the next grade and is viewed as a success in school. No-one considers a neurological examination warranted."

Crosby is in a minority position, in that he is prepared to consider dyscalculia as a possible explanation of mathematical underachievement. Many authors take the view that while other options are possible dyscalculia is an unnecessary concept. Thus Allerdice and Ginsberg [22] prefer to place the cause with teaching methods and teacher training, and emphasise that the fault does not lie in the child. They criticise the studies of Cohn [23], Kosc [3], and Weinstein [5] on the grounds that neurological indicators used are not causally tied to particular mathematical performances. But their attempts to show that the appropriate kind of teaching can eliminate underachievement is as much an argument for dyscalculia as against it. Particularly their illustration of two boys with apparent memory deficits underlying underachievement. One learnt the memory strategies he was taught and thereby improved, the other, although of adequate intelligence, failed to improve his memory - the authors do not give an adequate explanation. Magne [24] also appears to give some support to this position in his contention tht the error patterns of underachievers are similar to those of low achievers, are conceptual, and are learned. However, Magne also qualifies this by saying it is "from an overall point of view" and that "Individual variations are considerable". Moreover, Magne is clearly prepared to consider many more possibilities, and his position seems to justify our investigation in many respects, for he says :

> "Mathematics low achievement and underachievement appear to be complex and multifactored disabilities. I would like to stress this observation since we found it important and it justified a revision of the treatment theory we had started with.
>
> "In addition, I think we ought to accept the hypothesis that the causes may also be complex and multifactored."

Anxiety is another favourite explanation of mathematical underachievement; thus we find Buxton [21] devoting a book to this explanation, backed up by case studies of remediation by removal of anxiety. The fact that his subjects were able to make some progress with his help seems to have been sufficient to confirm the diagnosis. But these subjects were never seen by a neurologist, and were not shown to develop Mathematical talents commensurate with their general ability levels. This "anxiety" explanation is helped by articles such as that of Sepie and Keeling [25] who examined the relationship between three types of anxiety measures and mathematical achievement, and found that 'anxiety specific to Maths', but not 'general anxiety' or 'anxiety about school' correlated significantly with mathematical underachievement. But we should expect such an underachiever, whose

Mathematical performance falls far short of his general ability, to develop a specific anxiety towards Mathematics. Just as we should expect Buxton's remedial teaching to effect an improvement in performance, whatever the cause of the original difficulty (for we do not believe that dyscalculia implies an irremediable inability to do Mathematics), but perhaps remedial teaching based on other possible aetiologies might have proved even more effective.

Some of the literature does tend to exonerate some social and economic factors from primary involvement in underachievement; thus Magne [24] and Weinstein [5] found no social class involvement. This is in contrast to studies of backwardness, which usually find social class to be an important variable (e.g. Rutter and Yule [9]). It agrees with the finding on dyslexia, which is so far removed from the typical social class distribution of reading backwardness that it has acquired the label of 'middle-class syndrome' (e.g. Pavlidis [26], Critchley and Critchley [27]).

It may be significant that in the case of dyscalculia, as in dyslexia, of those interested parties prepared to accept the involvement of neurological factors in learning difficulties, neurologists are the most ready, psychologists somewhat less, and educators least ready (e.g. Critchley [7]).

STUDIES OF "DYSCALCULIA"

Kosc : One of the major studies of dyscalculia is that of Kosc [3]. Its importance lies in the fact that Kosc attempted the first precise 'neurological' definition of developmental dyscalculia, and also that it provoked a new interest in the area of mathematical difficulties and their origins.

Kosc attempted not only to define dyscalculia and to demonstrate its effect on children's Mathematics, but also to assess its prevalence and to classify different types according to the particular difficulties engendered. But this classification system appears to have been based largely on cases of acquired dyscalculia, and it is not clear that his use of it with "developmental dyscalculics" is fully justified or successful. That is, his paper is unclear in any distinctions between his initial classification of "patients" and his later generalisation of this classification to children.

We have already noted our objection to his use of a Maths. Quotient for identifying "potential dyscalculics" (see p. 4). However, in practice, when Kosc came to select his sample of "dyscalculics", he also used a mental age criterion, accepting only children with IQ greater than 90 (calculated from Koh's Block Design test, Goodenough's Draw-a-Person test, and the Terman-Merrill IQ test). Such a procedure will underestimate the number of "dyscalculics", since all those with low IQ will be missed, as well as those with very superior IQ who obtained average scores on his screening tests. Kosc's procedure actually produced 66 potential "dyscalculics" from the 375 children screened. These 66 children were then subjected to psychological and neurological assessment, and Kosc finally diagnosed 24 of them as "dyscalculic"; this gave a prevalence rate of 6.4%.

Kosc's screening test consisted of performance tests (counting the number of black dots in a schematic background of 10 x 10 dots; fitting cut-up shapes back into the original form) and arithmetic tests (+, -, x, ÷ for numbers $\leqslant$ 100; completion of sequences, and coding from letters to numbers). Groups who failed performance tests only, arithmetic tests only, or both sets of tests, were distinguished on many of the psychological assessment tests, and also on the neurological tests. The third group failed more often on both sets of measures; the children who failed only on the arithmetic tests were considered less likely to be dyscalculic and more likely to be emotionally disturbed; Kosc diagnosed them as not "dyscalculic" but suffering from a lack of knowledge of arithmetic facts.

Kosc's 'neurological' tests were based on the Gerstmann syndrome (Gerstmann [1]); they consisted of hand laterality, right-left orientation, finger gnosis, and spatial orientation. The psychological tests included ability to follow instructions, basic addition, copying a complex figure, arithmetic reasoning, writing words and numbers to dictation, spelling, digit memory, mental subtraction, speed and attention, reading comprehension and writing speed.

Finally, a neurological examination was conducted in which minimal brain damage (MBD) was inferred from distinct instability, lack of co-ordination, speech disorders, impaired attention, mild central flaccid paralysis, disturbed right-left orientation and disturbed finger gnosis. Kosc does not make clear how many children were involved in this examination, but his report that "of 13 children considered by the neurologist as gravely suspicious of objective pathological neurological finding, 10 were potential dyscalculics" implies that the whole sample was screened. If this was so, it contradicts the conclusions of Allerdice and Ginsberg [22] who criticised Kosc for having no control group for the prevalence of neurological signs, though we agree, as they say, that some of Kosc's data and procedures were sketchily presented.

In assessing Kosc's paper as evidence for the existence of dyscalculia, we need to ask :

(a) did he demonstrate impairment of basic mathematical abilities? Did Kosc's tasks relate to difficulties in learning and understanding Mathematics?

(b) did he demonstrate neurological impairment?

With regard to (a), there have been several studies of the ability to do Mathematics which suggests that there are special aptitudes for Mathematics and that these are at least partly genetically determined (e.g. Barakat [28], Krutetskii [20], Werdelin [29]). An analysis of several types of Mathematical tasks also reveals that many general abilities are also involved : the perception of numbers and symbols and their understanding; sequential and temporary ordering; memory, perception and understanding of relationships. But these are also mathematical abilities in the sense in which we have defined them.

Kosc certainly does not show impairment of any such specific ability in his sample, or spell out any specific ability necessary for any of his tasks, but intuitively his tasks do relate to mathematical performance. Moreover his subjects did tend to demonstate areas of impairment which were consistent from one task to another. For example, all the children who failed to copy the complex figure belonged to one of the groups who failed the initial performance tests - counting dots in a 10 x 10 array and fitting a cut-up figure back into its original form; whereas those who repeatedly failed to subtract 7 successfully from 100 tended to be those who failed the initial arithmetic tests.

With regard to (b), none of the children had been diagnosed as brain-damaged, and none were so diagnosed by the neurologist who examined them, so there was no unequivocal neurological impairment. The link between 'soft' signs and neurological impairment must be made via acquired conditions; that is, these 'soft' signs, or more extreme forms, are observed in acquired neurological conditions. To the extent that in such conditions the patient was free from 'soft' signs before the acquired condition, they may be regarded as indicative of neurological impairment. But this does not mean that when they appear in isolation they are also necessarily indicative of neurological impairment - they may or may not be. At present all we can say is that such signs are 'suggestive'.

The fact that such signs were more prevalent in the 'potential dyscalculic' group is also suggestive of a connection between them, but again there is no hard evidence.

To sum up, Kosc's article adds to the construct validity of dyscalculia, and suggests avenues for further investigation, without being in any way conclusive.

Weinstein : Weinstein's use of the word 'dyscalculia' implies specific mathematical retardation in the absence of obvious adverse social, emotional and educational variables.

Her 'dyscalculic' sample consisted of 14 4th-grade and 15 6th-grade American children selected from the 458 such children tested for their performances in Reading and Arithmetic on the Comprehensive Test of Basic Skills and the Otis-Lennon group IQ test, by the criteria

(i) at or above grade level in Reading

(ii) at least 11 months below grade level in Computational Skills

(iii) Otis-Lennon IQ $\geqslant$ 90.

Teachers' grading of the children agreed in 25 out of 29 cases with this method of selection. Weinstein's finding of 29 'dyscalculics' out of a sample of 458 (6.3%) is similar to Kosc's estimate, but is probably higher than Kosc's if Reading ability is uncontrolled as it was in his study.

Weinstein sets out to discriminate between three hypothetical causes of 'dyscalculia' :

(a) a broad block in Mathematics

(b) a maturational lag

(c) a specific deficit in some Mathematical ability.

Here (a) is hypothesised to be psychological in origin, caused by dislike of the subject, or of the teacher, or by anxiety; it is hypothesised to lead to random errors across mathematical tasks without affecting understanding of concepts, and without concurrent delay in development of concrete and formal operational thought (in the Piagetian sense). (b) is hypothesised to be due to a delay in maturation of mathematical processes and concepts with a concurrent delay in achievement of logical operations (in the Piagetian sense). It is hypothesised to lead to performance on mathematical and Piagetian taks which is typical of younger normal children, and to extend across areas of Mathematics (although Weinstein seems a little unsure of the latter prediction). (c) is hypothesised to be due to a specific neurological deficit and to lead to specific difficulty in some areas of Mathematics only, while other areas are normal. It is also hypothesised to lead to systematic errors which are not typical of younger normal children, and to be accompanied by signs of abnormal neurological functioning. Weinstein in fact tests only the hypothesis that the specific deficit is based on multiplication and extends across mathematical tasks which involve concepts based on multiplication (e.g. place value, division) and to Piagetion tasks involving multiplication of classes or dimensions. She also bases her sign of abnormal neurological functioning on Gerstmann's syndrome : impaired

Right-Left discrimination, dysgraphia (poor handwriting), finger agnosia (difficulty in discriminating between fingers by touch only).

It is clear that the linking of mathematical development with Piagetian development, and Weinstein's operationalisation of her hypothetical causal variables impose more or less severe restrictions on the ability of her research to support or not support each of the three hypothetical causes.

The research can also be criticised for the methodology adopted; that is, comparison of the 'dyscalculics' with a 'matched' control group (matched on sex, grade and IQ) who were at or above grade level in both Reading and Maths Computation. In fact her tables show that IQ matching (on the basis of a one-off group test) was not very close in some cases. This method always has the disadvantage that factors which have not been matched (such as parental help and encouragement, help with schoolwork at home, numbers and ages of siblings) may account for some of the differences between groups. In fact, it implicitly introduces and encourages a fourth hypothesis : that 'dyscalculia' is caused by some social, educational, emotional, or motivational factor not controlled for in the research.

On the basis of their performance on a large range of mathematical tasks, Piagetian tests and neurological tests, the 'dyscalculics' were compared with their normal controls for number and types of error. It was concluded that the broad block hypothesis received no support in that errors tended to be systematic and similar to those of younger, normal children, and were conceptual as well as purely computational.

There was also some evidence that some logical abilities were below those of controls, since some Piagetian tasks were more poorly performed by the 'dyscalculics'. The specific deficit hypothesis was weakly supported, in that the 'dyscalculic' group performed significantly worse than the control group on the finger localisation tests, and both handwriting and spelling were worse, but not significantly so, on the tests for dysgraphia. But R-L discrimination was not worse among 'dyscalculics'. However, the pattern of functioning of the older group of 'dyscalculics', which was found to be very similar to that of the younger controls in both mathematical and Piagetian tasks, including the methods used to solve mathematical problems (e.g. successive addition in multiplication tasks, counting on fingers, etc.), led Weinstein to favour the developmental lag hypothesis.

As we have already noted, both the specific deficit hypothesis and the maturational lag hypothesis, as used by Weinstein, arise from our definition of dyscalculia, and to the extent that Weinstein's results favour both these hypotheses, her research lends support to the existence of dyscalculia.

It is a pity that neither Kosc nor Weinstein have reported follow-up studies of their 'dyscalculics'. Although a finding that 'dyscalculics' eventually caught up with normals would not prove the maturational lag hypothesis (a specific deficit may have been overcome by means of a compensatory strategy, a non-neurological cause may have been removed), it would give us hope that non-intervention could be justified in the long term at least. On the other hand, a finding that dyscalculics dropped even further behind normals (as Rutter and Yule's [9] research suggested was the case for specific reading retardates) would emphasise the need for more research into the nature of dyscalculia and its remediation.

Slade and Russell : Slade and Russell [30] reported on four cases of 'dyscalculia' chosen on the basis of three criteria (i) bad performance on a series of clinical tests involving simple calculating and money problems; (ii) long-standing difficulties in doing arithmetic; (iii) scores on various psychological tests indicating severe backwardness in arithmetical calculation which was specific and could not be accounted for by a generally low level of intellectual functioning.

However, three of these cases had psychiatric problems, and the fourth was diagnosed as 'dyslexic'; so that in all these cases there are ready explanations other than dyscalculia for the poor arithmetic. Nevertheless, this study does give some support to the dyscalculia hypothesis.

The authors showed that, of the four basic arithmetical processes, multiplication was relatively more deficient and stemmed from a faulty grasp of basic multiplication tables. They went on to show that errors on the multiplication tables were due to a real, experienced difficulty rather than the result of carelessness, and that the degree of difficulty varied with the particular table involved.

They then attempted to alleviate these difficulties by two methods of coaching in the basic multiplication tables, with very little improvement in correct scores, although the time taken showed a large improvement. However, they had considerable more success with two methods to bypass the learning of multiplication tables - namely, provision of a printed set of tables for use in working out problems, and the teaching of a system based on a complex sequence of additions. It is interesting that Slade and Russell observed attempts by the children themselves to find strategies to bypass the learning of tables (i.e. dot notation for simpler calculations, e.g. 9 x 7; breakdown into simpler stages, e.g. 8 x 7 = (2 x 7) + (2 x 7) + (2 x 7) + (2 x 7); and gradual approximation, e.g. 102 ÷ 6 approximated by (8 x 6) + (8 x 6)). It is also interesting that on the WISC, all four were relatively weak on Digit Span (short-term memory) and Arithmetic subtests; and that three of the cases had large VIQ-PIQ discrepancies.

Slade and Russell found slight difficulties with R-L discrimination, and slight finger agnosia in three of their subjects (including the 'dyslexic') but no neurological signs in the fourth (whose VIQ and PIQ scores were similar).

The findings of specific areas of relative mathematical difficulty, the ineffectiveness of conventional remediation, the improvement due to compensatory strategies, and the finding of soft neurological signs all give some support to the dyscalculia hypothesis; but against this we must set the psychiatric status of these subjects, and the lack of 'neurological' signs in one of them.

STUDIES OF MATHEMATICAL UNDERACHIEVEMENT AND NEUROMETRICS

May : May [31] analysed data from a large-scale study of 11 year-old children, and showed that groups defined as 'Retarded in Mathematics' (i.e. underachieving relative to their general ability) and 'Backward in Mathematics' (i.e. low achieving relative to their chronological age level) were distinct, with only a very few children belonging to both groups. This distinction was similar to that found by Rutter and Yule [9] in their study of Reading achievement in children in the Isle of Wight.

This study shows that the selection of children for 'Mathematics disabled' or 'Learning disabled' groups which is done on the basis of performance relative to chronological age level, will almost certainly confuse the two groups, and exclude many high-ability dyscalculic or dyslexic children, while including low-ability children whose underachievement is only slight or non-significant. This probably explains some of the wide variation in results of studies of 'learning disabled' children.

Magne : The same distinction between 'retarded' and 'backward' was made by Magne [24] in his study of Mathematics achievement in Swedish school children. He estimated that 15% of children belong to the 'low achievement' (backward) group, while only 0.5 to 5.0% are underachievers, with even fewer underachieving specifically in Mathematics. Of those children experiencing difficulties with Mathematics, Magne said :

> "There are various aphatic syndromes, connected with more or less circumscript areas of the cortex, i.e. frontal, parietal and occipital lobes. Cases with clear-cut neurological disturbances are rare, but symptoms associated with the concept of minimal brain dysfunction or learning disability are also met, particularly correlated with specific dyscalculia."

Thus Magne found, as our definition of dyscalculia would suggest, that Mathematical underachievement, rather than low achievement, is correlated with neurological soft signs. Magne further differentiated the two groups by his observations that :

> "Low achievers often display symptoms of emotional and/or volitional disorders or a disturbed working disposition, involving lack of interest, home and/or school maladjustment, short attention span, lack of persistence, distractibility, limited initiative, insecurity or in some cases anxiety. Emotionally disturbed children particularly often display dyscalculia* as a symptom.
>
> "Abnormal social conditions have been found, but seem to be of less importance than intellectual or emotional/volitional disturbances *per se*. In some countries, but not in Sweden or Switzerland, it has been shown that parents of low-achievers in Mathematics tend to belong to the lowest socio-economic classes."

However, Magne goes on to say that personality disturbances are more frequent among under-achievers than low achievers and that probably these disturbances tend to cause the learning difficulties

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* Magne's use of dyscalculia implies only difficulties in Mathematics.

in Mathematics. This opinion seems not altogether justified, since he goes on to say that the personality disturbances decrease with school attendance, whereas Mathematical underachievement is only noticed after some length of schooling.

It has long been known that dyslexia tends to run in families (e.g. Orton [32]), and Magne noted that many low-achieving children had parents who also reported a learning-disability in Mathematics in their own schooldays. Magne does not regard this as evidence for a hereditory disability but rather as parental influence causing their children to feel insecure about Mathematics, and so inducing them to low performances, but the alternative conclusion needs to be acknowledged.

John *et al* : As part of a larger study of the neurological status of psychologically-defined groups, John *et al* [13] recorded brain activity in three groups of 9 year-old learning-disabled children : those with impaired reading and normal arithmetic, those with impaired arithmetic and normal reading, and those with impairment in both reading and arithmetic. They found abnormalities in recordings from the brains of all three groups; moreover, for the three groups these abnormalities were in different frequencies depending on the group, and for the second group the abnormalities were also in a different cerebral hemisphere (the Right hemisphere).

Rourke and Finlayson : A similar finding of differential hemispheric performance was reported by Rourke and Finlayson [33] when they compared 45 9 to 14 year-old reading-disabled or arithmetic-disabled children on a number of measures. The pattern of abilities revealed by subtest scores on the WISC suggested a left-hemisphere deficit for the reading-disabled, and a right-hemisphere deficit for the arithmetic disabled.

This study, and the findings reported by John *et al*, suggest that arithmetic disabled children, in whom the disability is specific to arithmetic, may have abnormal brain functioning in the right cerebral hemisphere, as shown by both ability patterns and direct recordings from the brain. This is probably the most direct evidence we have that mathematical difficulties are in some cases directly related to abnormal brain function, and strongly supports the existence of dyscalculia.

STUDIES OF ACALCULIA AND NEUROPATHOLOGY

Several authors have pointed out certain similarities in performance of learning-disabled and brain-damaged subjects. While it is dangerous to infer causality from such camparisons, it would be foolish to disregard them altogether; and remedial techniques developed from one may be beneficial to the other.

One syndrome in particular has been associated with acquired dyscalculia. Now referred to as Gerstmann's Syndrome, it was described as early as 1899 when Anton (a physician) reported a case of arithmetic difficulties combined with Right-Left disorientation, inability to write (dysgraphia), and difficulty in naming or counting fingers (finger agnosia). Similar symptoms were reported by Hartmann in 1902, van Woerkorn in 1919, Bonhoeffer in 1922 and Gerstmann in 1932. Gerstmann [1] thought the syndrome was the result of head injury to the dominant (left) parietal or parieto-occipital region.

In 1937, Guttmann [34] raised the possibility of a developmental Gerstmann syndrome. This suggestion has appeared sporadically in the literature since then : Critchley riased the possibilty in 1942 but doubted it later [35]. Kinsbourne and Warrington [36] in 1963 presented seven case reports in support of its existence, but only two were presumed to be congenital defects, the other five were thought to be due to perinatal trauma. Kinsbourne and Warrington characterised the 'Developmental Gerstmann Syndrome' by : failure on tests of finger differentiation and order, poor penmanship and difficulty with spelling, Left-Right confusion, poor spatial and constructional performance, PIQ<<<VIQ, and very poor arithmetical performance, both written and oral. They suggested that there is no absolute deficit, and that the condition is due to a developmental lag which will be cured by training and maturation. Benson and Geschwind [37] in 1970 reported on two cases of 'Developmental Gerstmann Syndrome'. These cases were similar to those of Kinsbourne and Warrington, except that the one with lower general ability had only 4 points difference between VIQ and PIQ.

Other important studies have revealed alternative syndromes, though amongst these there are still some aspects that overlap with those of Gerstmann's syndrome.

Henschen [38] was the first to study 'acalculia' in detail, and 'acalculia' for him included disturbances in number recognition as weli as in arithmetical operations. He observed it as a clinical manifestation of lesions located in widely disparate regions of the brain, but he believed that a common anatomical involvement was the caudal portion of the left cerebral hemisphere.

Pick [39] presented data in support of his idea that arithmetical difficulties are associated with temporo-occipital lesions, and are closely related to defective comprehension of shape. But he allowed that if the patient was unable to solve particularly complex problems then the anatomical lesion might be in the frontal regions.

Head [40] systematically studied arithmetical ability in patients, using addition problems of graded complexity. He concluded that it was impossible to determine the type of the presenting clinical aphasia (on his classification) by arithmetical operations alone. But in severe 'nominal' aphasia, which resulted from lesions primarily in the angular gyrus of the dominant hemisphere, profound confusion in numerical sequence and comprehension of the meaning of numbers occurred.

Critchley [41] distinguished different manifestations of acquired dyscalculia : verbal deficiencies which included handling numbers as words, recognising symbols, and perseveration; spatial-constructional difficulties which included arranging numbers of paper and the idea of arrangement before performing operations on numbers; and ideational difficulties, including understanding the meaning of numbers, the slowing down of number operations, no memory for numbers, poor use of operator and separator symbols, orders of magnitude, concepts of the four basic operations, part/whole relations, and place-value concepts. He admitted that there is some evidence that particularly spatial and ideational difficulties may be due to Right hemisphere damage, but held that more cases of acalculia arise from major-hemisphere than from minor-hemisphere lesions.

Cohn [42] disagreed with Critchley on the latter point. Reporting on more than 40 adult brain-damaged patients with acquired dyscalculia, he investigated Maths. deficits by ability to multiply sequences of 3- and 2- digit numbers. The defects observed included : disturbed horizontal positioning of number sequences, disarray of the vertical alignment of numbers, failure to use separating lines to differentiate operators from products, transposition of number pairs or sequence reversals, faulty memory for tables, inability to recall the operational symbol, failure to 'carry' correctly, and perseveration of delineations. Such defects never occurred as isolated clinical phenomena in his series of patients. He found that 'dyscalculia' occurred in nearly half his cases of minor hemisphere damage. He concluded that 'dyscalculia' may result from lesions in widely disparate regions of the brain, that lesions disturbing the physiology of central visual apparatus profoundly alter the processes of arithmetical 'order', and that where the visual system is not affected disturbed memory processes primarily generate the observed arithmetical deficiencies.

Hecaen *et al* [43] postulated three types of 'dyscalculia' on the basis of their study of 183 brain-injured subjects : verbal 'dyscalculia' (due to left-hemisphere damage) including figure or number dyslexia; visuo-spatial 'dyscalculia' (due to right-hemisphere damage), and anarithmetica or ideational 'dyscalculia' (due to wide-spread brain dysfunction). These categories are very similar to those of Critchley, but the locations of damage are more precisely tied to the categories.

No collection of diagnostic material has been accumulated for looking specifically at dyscalculia, but we shall see later in this thesis that the battery of tests we selected for looking at our case-study children from local schools, begins to separate the mathematically underachieving children into categories which relate to those above found in cases of acquired acalculia.

GENETIC FACTORS IN MATHEMATICAL DIFFICULTIES

One well-documented finding, which may be a small pointer to possible genetic involvement in Mathematical ability, is the superiority of boys, at least from adolescence, in areas of Mathematics other than mechanical arithmetic, particularly in those areas involving spatial factors. This finding has been variously explained in terms of child-rearing practices, conformity to expectations, differential amounts of practice, emotional variables, biased samples, etc. (e.g. Sherman [44], Hashway [45], Benbow and Stanley [46], Stamp [47]). Nevertheless, the dearth of creative women Mathematicians in all societies, and the failure of women to win prizes and medals in Mathematics competitions, still seems to warrant more explanation - especially as a proportion of women (anecdotally at least, the more mathematically able) do become Mathematicians.

A much more concrete piece of evidence of genetic involvement is the widespread finding of depressed arithmetic scores in cases of Turner's Syndrome (45 X O chromosomes - female). Money [48] found that the depressed arithmetic score occurred together with low perceptual organisation scores on the WAIS (in block design and object assembly subtests).

This was also found by Pennington *et al* [49] who concluded that Turner's syndrome was associated with a spatial deficit such that subjects had higher Verbal than Performance abilities, and that this was true as early as 4 to 5 years of age.

Autopsy findings on Turner's syndrome patients were reported by Reske-Nielsen, Christiansen and Nielsen [50]. While one brain was relatively normal, the other showed several abnormalities, especially in the Right-hemisphere. They also quoted a neuropathological report by Brun and Sköld [51] on a 16 year-old girl with Turner's syndrome, again showing Right-hemisphere abnormalities. The authors concluded :

> "The functional disturbances seem mainly caused by aberrations in the posterior right-hemisphere and the corresponding basal areas. It is thus not a question of a diffuse cerebral developmental anomaly, but, on the contrary, a decreased function in relatively delimited cerebral areas, even if there are quantitative individual variations."

EVIDENCE FROM DYSLEXIA STUDIES

As we have already mentioned, dyslexia is a parallel disorder to dyscalculia, which affects language functions (particularly reading and spelling) rather than Mathematics. The number of studies dealing with dyslexia is, however, several orders of magnitude larger than the number dealing with dyscalculia, and consequently much more is known about the disorder. (At the start of our project, a computer search of the literature yielded only a handful of items for dyscalculia, but hundreds for dyslexia). In spite of all these studies, there is still no single agreed definition and the literature abounds with idiosyncratic choices of groups of 'dyslexics', and with contradictory findings.

Notwithstanding the many confusing definitions of dyslexia, one of the most convincing findings for the existence of dyslexia when defined analogously to our definition of dyscalculia, comes from reports of autopsies performed on 'dyslexics' who had been diagnosed from specific difficulties with language functions, especially reading and spelling, which were developmental in kind, in the absence of adverse educational, social, emotional, and motivational factors. Two out of three of these cases had earlier been found to have normal EEG recordings. Although two out of three of these cases had other abnormalities at the time of death, all three presented abnormalities of the Left-hemisphere at autopsy - notably mis-formed cells and cells in abnormal locations [52][53].

Clearly a condition which can only be reliably diagnosed at post-mortem is not very useful in practice, but Pavlidis [26] claims to have a test which separates dyslexics from other specific language-impaired subjects, namely, eye-movements, not only in reading but also in trying to fixate any material (a series of coloured lights, specifically) in order. As he defined dyslexics, this series of tests separated his dyslexic group completely from other groups such as 'backward readers' and 'normals'. Pavlidis does not subscribe to the view that abnormal eye movements cause dyslexia, nor to the more usual view that dyslexia causes abnormal eye movements, but thinks that both occur as symptoms of a common neurological cause. There is as yet no convincing theory linking eye movements with language difficulties in a neurological framework, so that it is not possible to assess the likelihood of finding abnormal eye movements in all cases of dyslexia (as Pavlidis proposes); it may be that such a co-occurrence defines only one type of dyslexia. Such a view would be more in line with our definition of dyscalculia.

Much research tends to look for commonalities in dyslexic functioning. This is a legitimate exercise since, in a large group of dyslexics, we should expect some deficiencies to be common to small subgroups (such as are found among large groups of acquired dyslexia cases), but we should not expect all dyslexics to display the same abnormalities. This qualification probably explains why a factor which reaches significance in one group of 'dyslexics' (e.g. left-handedness, cross-laterality, disturbances of temporal order, poor Right-Left discrimination, phonetic errors, semantic errors, etc.) fails to be significant in another group.

One of the most convincing theories to come from this 'commonality' approach is Miles' [16] suggestion that dyslexics have difficulty with verbal encoding; and in particular that those parts of the brain which mediate this process are defective or immature. This would also give rise to disturbances of temporal order (e.g. Bakker [54]) in verbal material.

Most authors now see dyslexia as a multi-factorial disorder, and many different classifications have been proposed. For example, Kinsbourne and Warrington [55] classified the condition by the academic areas affected, e.g. Reading + spelling; spelling + arithmetic; Reading + spelling + arithmetic. Crosby [12] classified by the types of error committed, into 'aural dyslexics' and 'visual dyslexics'. With regard to aetiology, Crosby also quoted the theory that this distinction between 'aural' and 'visual' dyslexics may parallel the incidence of familial and non-familial cases of dyslexia - the non-familial cases arising from minor brain-damage at birth.

SUMMARY OF LITERATURE

While this review of the literature has produced no overwhelming evidence in support of our concept of dyscalculia, the small pieces of evidence from such a diversity of sources must be seen as a sound basis for the construct validity of dyscalculia as a disability in Mathematics leading to mathematical underachievement caused by neurological impairment which is genetic or congenital.

We now turn to our own proposed investigation and the methods we propose to adopt, which we hope will cast further light on the construct validity of the concept.

METHODS OF INVESTIGATION

Since we have defined dyscalculia in terms of mathematical underachievement, our first steps will be to find children who are underachieving in Mathematics. Two sources will be used, and will lead to two different types of investigation. The first of these sources is a national study involving some 18,000 children born in one week in March 1958; the second source is local schools who have agreed to nominate children who are underachieving in Mathematics. In general terms, the former will lead to a 'population' study, the latter to a 'clinical' study. In fact the former will be an exercise in data analysis, using pre-recorded data, in which we shall have to choose what we judge to be relevant variables for our study. Having selected our group of mathematical underachievers, on the results of Mathematics and General Ability tests, we shall then compare this group with the total population on our selected range of 'relevant variables'. The 'clinical' study, on the other hand, will involve the selection of a battery of tests, and its administration to the case-study children, with an analysis of the results, being related to the 'population' study by our choice of tests and variables.

There are methodological strengths and weaknesses in all research approaches, but the availability of data from the largest and most comprehensive child study in this country, coupled with work with individual children, provides two complementary avenues of investigation. Limitations are likely to appear in both areas - particularly in the pre-selected nature of the variables (albeit over 1500 of them) in the NCDS data, and the variation amongst schools and individual teachers in their diagnosis of underachievement, but these are discussed in more detail with the results.

Other more general limitations have been highlighted in the literature, by Meichenbaum [56] for example, and these too will be weighed up in relation to the investigation. In particular, Meichenbaum made some critical comments on the two strategies used here, basically

(1) the population comparison strategy in which LD and normal children are compared on a battery of psycho-educational tests, and the nature of the deficit is inferred from the differential pattern of performance,

(2) the specific deficit analysis strategy in which a specific deficit is hypothesised, and then the investigator attempts to assess that deficit through a battery of tests.

His main criticisms were that such methods assume that performance can be separated into specific units or functions, each of which is independent and capable of being individually evaluated and/or exercised; that individual differences are lost, treated as error variance, in group means; that describing a learning difficulty in terms of performance on a set of tests might lead to circularity; and that the experimenter's concept of the specific deficit hypothesised determines whether or not it is found.

However, Meichenbaum's own prescriptive method :

(3) a cognitive-functional method, in which he advocates treating each case as unique, using investigation only to effect remediation of symptoms, using "introspection by the investigator and by others" to determine task-relevant strategies with which to compare those of the subject, and only later, on the basis of experience with many subjects, to look for commonalities,

is also open to criticism. Firstly, *ad hoc* remediation may be partially successful but leave a deficit in some other area which will appear later; secondly, comparison of strategies is open to the objections that the experimenter's strategy is not necessarily the only, or the best, available, that it tends to prejudge the subject's difficulty as one of strategy choice, and it assumes that the subject is not suffering from a deficit which would make such a strategy impossible for him; and thirdly, since each individual case is beset by idiosyncracies (e.g. in severity, consistency, and compensatory strategies used, in a given disorder) commonalities might not be recognised amongst irrelevant details.

As noted earlier, limitations are bound to occur in any method but, provided that the limitations of the method are recognised, particularly when interpreting results, and that the pitfalls mentioned are avoided, we feel that they each can, and have, yielded valuable results.

We are looking for evidence of neurological deficits in mathematically underachieving children, and the first of our methods, mentioned above, will be to compare such children with a 'total population' of children. We recognise that in so doing we are dividing our measurements into separate units (e.g. we shall have no measures of 'social environment', 'academic environment', 'personality', etc., but only measures such as 'social class', 'family size', 'school size', 'parents stayed on at school', 'child's activity level assessment' 'child is often tearful', etc.). On the other hand, we think that the different but not necessarily distinct set of measures we are using has advantages over any single 'overall' measure. The various factors can in fact be combined to give a global measure, but in addition enable us to look at individual factors. Expert opinion is based on an assessment of a collection of such individual measures; in some cases we do use the individual measures to compute a global measure which agrees well with expert opinion derived from individual assessments based on interviews with the children concerned (e.g. the Bristol Social Adjustment Guides [57] score agrees with psychological assessments of 'maladjustment'); and the measures used were those thought most relevant by the panel responsible for the NCDS questionnaires, and to that extent represent the common view of the importance of the various measures as a factor in global assessment (thus tending to eliminate the idiosyncracies of any single assessor).

We also recognise that we are merely sampling a range of behaviour in our achievement tests, ability tests, social adjustment assessments, etc. But all the tests used have high reliabilities; moreover, in most cases we have teachers' assessments with which they can be compared, and these assessments are based on behaviour over months or years. Further, as will be seen in later chapters, we have not been looking primarily at marginal variations, but at large variations in performance or extremes of behaviour. And, although statistical methods may hide individual variations, they do have the merit of smoothing out random errors, such as may be expected due to the one-off test situation.

Bearing in mind this latter point, however, it does mean that when mean scores are used we may lose some important individual differences, especially when choosing to compare an experimental group with a 'total population' which includes that group. This method of comparison is nevertheless justified by the relative sizes of the experimental groups and the population; it will, however, make any real differences less apparent, that is, we shall err on the side of Type I errors. In the circumstances, we feel that this is an appropriate stance to take, since it is less likely to lead to false claims in favour of our hypotheses.

One other factor to be borne in mind when using a complete sample of all the children born in a certain period is that, in addition to children who will attend normal schools, it will also contain abnormal subgroups (e.g. brain-damaged ESN children) having some of the characteristics for which our experimental groups are being tested. For this reason, some comparisons will also be made with very large subgroups of the population (e.g. chosen by ability level).

Overall, in both our large-scale study and in our individual studies of local school-children, we realise that the battery of tests used cannot be exhaustive, and that, at most, we shall only find significant variations in the particular variables included in our tests. The study cannot therefore preclude the possibility of other relationships in mathematical underachievement to justify the concept, but it will look closely at likely factors arising from the literature and the various experimental procedures.

THE SCOPE OF OUR INVESTIGATION

The aims of our investigation were stated on pages 7 and 13 of this chapter. Because this is a preliminary investigation, we have chosen to make these aims and our general approach as wide as possible. Until we have investigated the existence of dyscalculia, and particularly the identification of dyscalculics, and possibly broad 'types', we feel that it would be premature to attempt any categorisation of mathematical learning difficulties in dyscalculia.

However, as we shall be looking closely at children in schools who may be dyscalculic, and in some cases observing their mathematical performances, we shall bear in mind suggested classification systems, with a view to suggesting profitable directions for further research. For example, whether it would be possible or profitable to pursue the dichotomy suggested by Kinsbourne [58] of disorders of 'processing' and those of 'attentional focus'; the former giving rise to more selective difficulties, and the latter extending to all types of subject matter. The processing disorders would be further categorised into distinct subtypes demonstrable at different levels of analysis (including achievement profiles, error-type profiles, intelligence profiles, and developmental profiles). Adequate behavioural analysis would involve identifying a particular syndrome by its characteristic pattern of abnormality at each of these levels, and then at the neurological level attributing this behavioural syndrome to neuronal insufficiency at some particular location in the central nervous system.

Or would it be more profitable to ask : where does the breakdown in functioning occur? In the input stage, the processing stage, or the output stage? Breakdowns in each of these stages have been reported by various researchers using widely different groups of 'learning-disabled' children, but no specifically mathematical-disabled groups. Considering the input stage, Leisman and Schwartz [59] proposed that occular-motor variables may be implicated in some reading disorders. They investigated the saccade characteristics of children and brain-damaged adults and showed that reading-disabled children and adult hemiplegics had saccades of significantly shorter duration and higher velocity. It was hypothesised that these would not allow enough time for transmission of information, with consequential effects on visual processing, leading to segmentation, inability to achieve fluency transpositions, the skipping of words, and so on. Similar lines have been pursued by Pavlidis [26]. Considering the output stage, Goodman [60] compared 'impulsive' (typically, hyperactive) children with 'reflective' children on Kogan's Matching Familiar Figures Test. The 'impulsive' types rarely looked at the standard or searched all the alternatives, their visual scanning was global, non-analytic and unsystematic. Yet when they were asked how they would advise other children to do the same task, they produced an efficient strategy - the same one produced by the more successful 'reflective' group. They seem to have analysed the task and seen what was required, but their actual performances were not related to this. Most researchers have concentrated on the processing stage, and there are many hypothesised processing deficits. One of these which may be significant in dyscalculia, is poor short-term memory which Kleuver [61] has suggested may lead to poor reading (when the child is unable to remember the beginning of a word or sentence while he scans its end) and mental arithmetic (where numbers have to be retained in memory while performing the mathematical operations).

Or it may be that a less abstract, more operational system of classification, such as that proposed by Critchley (see p. 35) and Hacaen (see p. 37), would be more useful.

We certainly hope that pointers towards a classification system, perhaps unlike any of the above examples, will arise from our case study investigation, and suggest new directions for research.

A NOTE ON THE STRUCTURE OF THIS THESIS

Each chapter deals with a particular topic in our investigation, and consists of a short summary or introduction, a survey of the literature related to the topic dealt with (where appropriate), our own work on the topic, and finally a short summary of our results and a bibliography (where appropriate).

Large amounts of material which might obscure the main arguments if presented in the text (e.g. raw data) have been included as appendices.

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CHAPTER II

THE NCDS AND PRELIMINARY INVESTIGATION

This Chapter begins with a general description of the National Child Development Study (NCDS) data; and considers the conception of the study, its implementation, missing data, reliability of the variables, and some relevant published results. The usefulness of the data for our purposes and some of its limitations are derived from these descriptions.

THE NATIONAL CHILD DEVELOPMENT STUDY DATA

I. Design and Collection of Data

The National Child Development Study (NCDS) began as the Perinatal Mortality Survey (PMS), sponsored by the National Birthday Trust Fund. The formation of the PMS was due to Professor W.C.W. Nixon, who proposed such a survey on his return from the World Health Organisation Symposium in 1953. A pilot study in Norwich encouraged the instigation of a national survey.

The ideal procedure for this survey, for an enquiry which would follow a large number of women from early in pregnancy to its termination, proved impractical, due to late diagnosis, late bookings and multiple places of prenatal care. It was therefore decided to identify subjects for inclusion at delivery or death of the baby, collecting available information about the mother's background, her pregnancy and labour, with a detailed necropsy enquiry in cases of stillbirth and neonatal death.

The PMS began in 1958 and took the form of a questionnaire, completed by the midwife in attendance at delivery, after consultation with the mother, doctors, and all available records. This questionnaire (68 items) was compiled by a team of experts with a view to examining many aspects of perinatal mortality. Its scope was wide, including social and family background, past obstetric history, antenatal care, abnormalities during pregnancy, length and abnormalities of labour, analgesia and anaesthesia, and the sex, weight, progress, management and outcome of the infant. The completed forms were checked by the midwives' supervisors, returned to the local Medical Officer of Health, and checked against official records of births and deaths.

The survey attempted to include all births in England, Scotland, and Wales in the week 3rd to 9th March 1958 inclusive (the control week), and these children also formed the basis of the NCDS. Since this sample of 17,205 babies included so few deaths (666), a survey of stillbirths and deaths only was continued throughout March, April and May. Statistical comparisons were made between singleton deaths over the 3 month period and singleton live births in the control week [1].

An estimation of the total births from notified and registered births, showed that the Survey returns of questionnaires were 98% of the estimated figures; and that stillbirths and neonatal deaths in the Survey were 94% of the estimated total, based on March, April and May figures.

A very brief summary of some of the findings will be presented later in this Chapter as they may have some bearing on the aetiology of underachievement; detailed findings are in Butler and Bonham [1].

In 1964, the Central Advisory Council for Education commissioned the National Children's Bureau to carry out a follow-up of the children born in the control week of 1958. At the time there was no firm commitment to further follow-ups. The short-term and long-term goals, as summarised by Pringle, Butler and Davie [2], were then :

"(a) To study the educational, behavioural, emotional, social, and physical development of a large and representative group of British children in order to gather normative data; to investigate the complex inter-relationships between the many facets, both normal and deviant, of children's development; and to report the incidence of handicaps and the provision currently being made.

(b) To utilize the uniquely comprehensive perinatal data already available, in an evaluation of the relationships between conditions during pregnancy and at birth, both social and medical, and the development of children in all its aspects at age 7. From this investigation ... to determine some of the factors at birth which place children 'at risk' of developing handicapping conditions. Such information should permit early identification of 'vulnerable' children so that earlier diagnosis and treatment, or provision, will be possible. The kinds of disability about which this sort of information is needed are not only the grosser forms, but also the more numerous 'minimal' handicaps which, if undetected, at best prevent children from realizing their full potential, and at worst cause grave psychological damage due to the covert nature of the difficulties."

and in the longer term :

"(a) To explore the constancy and change in the pattern of children's development longitudinally, and to investigate the associated educational, environmental and physical factors.

"(b) To follow the progress - over a long period - of those children who at birth might be 'at risk' in order to evaluate possible latent effects, and also to examine any post-natal factors, environmental, educational or medical, which may minimize a handicap.

"(c) To identify and follow the progress of children who at 7 years of age are already handicapped or show-ing signs of difficulty; those who because of adverse social or other circumstances might be considered 'at risk' of becoming educationally backward or socially deviant; and those who display exceptional talent or aptitude.

"(d) To evaluate the efficiency of medical and educational provision for handicapped, deviant, and exceptional children.

"(e) To identify groups of children of special interest, including many of those enumerated under (c) and (d) above, so that intensive studies may be mounted by expert teams. This would permit much more detailed and comprehensive investigations of the factors involved against a 'backcloth' of the necessarily cruder data gathered in the follow-up of the whole cohort."

The first follow-up occurred in the last few months of infant school, when the children were just 7 years of age. The children from the PMS were traced, and tests and questionnaires were designed by panels of experts. Chiel Education Officers and Principal School Medical Officers undertook arrangements for completion and return of tests and questionnaires, and the prior distribution of letters to schools and parents. The materials used were an 'Educational Assessment' booklet and five tests (for completion or administration by schools); a 'Parental Questionnaire', usually completed by a health visitor in an interview with the mother; and a 'Medical Questionnare', completed by a school medical officer on examination of the child.

A summary of the Educational tests is given below with some appraisal from scrutiny of the literature and the actual tests used:

(1) The Bristol Social Adjustment Guides [3] - an index of behaviour as rated by the teacher; the teacher underlines those descriptions of behaviour, from 250 given, which best fit the child. This test gives a quantitative assessment of deviant behaviour.

(2) The Southgate Reading Test [4] - a test of word recognition; the child selects from a list of words the one that corresponds to a given picture and identifies from a list of words the one read out by the teacher. This test differentiates backward readers very well, but has a rather low 'ceiling'.

(3) The Copying Designs Test - a test of perceptuo-motor ability; the child copies simple shapes. Reliability is affected by poor motor control, but the test is quite good at diagnosing real perceptuo-motor problems.

(4) The Draw-a-Man Test [5] - a test of mental and perceptual abilities and of maturity. The child is asked to draw a man - the best he can manage. The test is not very reliable on its own, since artistic ability and practice are not controlled.

(5) The Problem Arithmetic Test - simple problem-solving involving easy arithmetic covering the four basic operations. Only one problem involved more than one basic operation. Problems were chosen from a large number previously well-tested and used by the NFER, and selected on their known facility values so that the complete test would produce a normal distribution of scores. Questions were read out to poor readers. No overall reliability was calculated.

All Questionnaires were designed so that : the data could be transferred to punched cards, and as many answers as possible were in pre-coded form; and no transcription sheets were required in order that coding could be done directly from the forms themselves.

The 'Educational Questionnaire' covered type, size and structure of the child's school; size and structure of his class; contact between school and home; social class of parents of children attending the school; and the abilities, adjustment, behaviour, and parental interest and support of the child, as assessed by teachers.

The 'Parental Questionnaire' was a compromise between the needs for current data and retrospective data covering the period between this follow-up and the PMS. In general, priority was given to contemporary data and data thought to be generally more reliable or for which checks (e.g. medical records) could be made. The child's medical history, from the parents' viewpoint, was including in this questionnaire. Also included were : social class (occupations of parents); family size; home moves; pre-school experience; separations from mother; the child's general emotional and behavioural states; parent-child contacts and relationships as assessed by the mother; and the physical home environment and facilities.

The 'Medical Questionnaire' was designed to provide uniformity; administration of tests of function, and examination of the special senses was specified in detail; answers were pre-coded but provision was made for written amplification of answers to each question. The questionnaire covered the child's medical history (exactly matching the corresponding portion of the Parental Questionnaire); height, weight, head circumference, tests and assessment of vision, speech and hearing, including an audiogram; a urine test; tests of motor co-ordination and laterality; and a full clinical examination.

These questionnaires can be found in Pringle, Butler, Davie (1966)[2].

Completed forms were double-checked by hand for completeness, coding errors, certain logical inconsistencies, and accuracy of scoring; some errors could be rectified by reference to other parts of the questionnaires. The data from this Survey was amalgamated with that from the PMS at the stage of transfer to punched cards. The data were then edited by computer for incorrectly coded and mis-punched information.

The second follow-up, in 1969, was undertaken by the National Children's Bureau. It was designed to assess the children in their final year of junior school, at the age of 11. Questionnaires and tests, similar to those administered at age 7, were used. There were several modifications; most of these involved the replacement of less relevant questions, non-duplication of some material, and the inclusion of new relevant material (e.g. pubertal development on the Medical Questionnaire). There was also an additional Questionnaire to be completed by the child himself; it covered out of school activities, staying on at school, favourite school subjects, and how the child imagined himself at the age of 25.

The Educational Tests consisted of : an Ability Test; a Reading Comprehension Test; a Mathematics Test; and a Copying Designs Test. These will be considered in more detail since they form the basis for our identification of various groups of children.

The Ability Test was designed by the NFER; it consisted of 40 Verbal and 40 Non-Verbal items, given alternately. The questions were of the multiple-choice design, and examples of the two types, V and NV, are shown in Figure 2.1.

FIGURE 2.1

Examples of (a) Verbal; (b) Non-Verbal Items in the Ability Test

(a)

	Yard			Stone	
Foot		Mile	Pound		?
	Inch			Ounce	

Penny, Ton, Pint, Hour, Gallon

(b)

	b			M	
b		b	M		?
	b			M	

Σ W M̄ M Σ

The instructions given to the children were :

"In the example below, four words on the left go together in the same way as four words on the right, but one of the words on the right is missing. Find out how the words on the left go together and then put a line under the missing word in the list of words given."

and

"Here is another example using shapes instead of words. Find out how the shapes on the left go together and then put a line under the shape that is missing from those on the right."

One of each type of item was done as an example and four practice items of each type were to be completed by the children before beginning the test.

The reliability of this test (using Kuder-Richardson Formula 20 (N = 363) was 0.94. Verbal and Non-verbal combined correlated 0.93 with NFER Verbal Test 8A. It also had a strong relationship with examination results at 16 years (personal communication).

The Reading Comprehension (RC) test consisted of 35 sentences, in each of which one word was omitted. The children had to choose, from a list of 5 words, the correct word to complete the sentence.

Two completed examples were given :

"A bird lays its eggs in a (pond, stream, cloud, house, nest)."
"Bread is made from (wood, flour, grass, stone, salt)."

Children were encouraged to guess if they were not sure of an answer.

This test was specifically constructed by the NFER to be parallel to the Watts-Vernon Test of Reading Comprehension. Its reliablity, using Kuder-Richardson Formula 21 (N = 300) was 0.82.

The Ability Test and the Reading Comprehension Test were to be administered in that order on one day. The next two tests, Copying Designs and Mathematics, were to be administered in that order on a different day.

The Copying Designs Test presented children with 6 shapes, each to be copied twice. These shapes included a circle, a triangle, a square, a diamond, a cross, and a 4-pointed star. The child was instructed to copy each design as carefully as possible in pencil. No straight-edge was allowed.

The Mathematics Test was also constructed specially by the NFER for use with this age group. It contained mechanical and problem items, and tested a wide range of mathematical skills; there were 40 questions altogether. Reliability, calculated using Kuder-Richardson Formula 21 (N = 300) was 0.94.

The third follow-up, in the children's last year of compulsory education, 1974, was again undertaken by the National Children's Bureau. The range of instruments used was similar to the 1969 follow-up, but unfortunately, in our view, no Ability tests were given, and the Individual Questionnaire, completed by the child himself, was greatly extended.

In 1974 the study children had their sixteenth birthdays; it was also the year in which the school leaving age was raised to 16, so there was some emphasis on future careers, and how the extra compulsory school year was seen by children and their parents. The children were also asked to assess their own abilities in a range of school subjects.

On the 'Educational Questionnaire', teachers were also asked to rate the children on a wide range of school subjects, as well as to assess their suitability, or otherwise, for various types of further education.

Two Educational Tests were administered: the same Reading Comprehension Test as in 1969, and a multiple-choice design Mathematics Test, specially constructed by the NFER for this Survey. Reliabilities, calculated using Kuder-Richardson Formula 21 ($N = 300$) gave $r = 0.86$ for the RC Test and $r = 0.85$ for the Mathematics Test. No validity coefficients were given, but there were close relationships between results of these tests and examination results at CSE and 'O'-levels.

Missing Data

In assessing the NCDS data as a basis for our own investigation, we need to consider the degree of Missing Data, its treatment by other users of the NCDS data, and our own investigation of how it might affect our results. We also present a few published results of analyses of the data by other authors, very few of whom, however, have taken account of the effects of missing data.

Two main types of missing data at each follow-up can be distinguished : cases where no information at all exists, and cases where individual items, or individual questionnaires, are missing.

The former type arises from cases of parents' refusal to participate in the Survey, cases of children who could not be traced, and cases of children who had died or emigrated. The first of these categories, partents' refusal, grew with each follow-up, from 0.5% of the PMS children to over 6% of children at age 16. The second category is probably biased towards children in families which moved frequently.

Missing individual items or questionnaires may be due to refusals to answer, difficulty in categorising an answer, home circumstances which made a parental interview or medical examination impossible, or parents who failed to keep appointments.

The total number of children grows with each follow-up due to (a) retention of children from previous stages who had died or emigrated, and (b) addition of immigrant or previously untraced children with appropriate birthdays (who necessarily have early records missing).

Table 2.1 shows the incidence of missing data of the first type at each stage of the NCDS project. (Taken from Fogelman [6]).

TABLE 2.1

BASIC DISTRIBUTIONS (PERCENTAGES)

	Age	Total	Some data	Refusal	No data*	Untraced*	Emigrant at sweep †	Deaths since and including previous sweep
(a)	Birth							
	All children	100.0 (N=17733)	98.2		1.8		-	-
(b)	7 years							
	All children	100.0 (N=18118)	85.0	0.5	7.7		2.3	4.5
	(Excluding deaths and emigrants)	100.0 (N=16883)	91.3	0.5	8.3		-	-
(c)	11 years							
	All children	100.0 (N=18365)	83.3	4.5	3.9		3.8	4.5
	(Excluding deaths and emigrants)	100.0 (N=16835)	90.9	4.9	4.1		-	-
(d)	16 years							
	All children	100.0 (N=18578)	79.5	6.2	2.3	3.1	4.3	4.7
	(Excluding deaths and emigrants)	100.0 (N=16915)	87.3	6.7	2.5	3.4	-	-

* At the ages of 7 and 11 years, for technical reasons, the separate figures for 'No data' and 'Untraced' are unavailable.

† Some of the emigrants at earlier ages return later and are included in the above figures. In all 1013 children had ever emigrated by the age of 16 (5.5 per cent of the sixteen-year-old total).

Detailed studies of the effects of missing variables on the data at 7- and 11-years appear to have been neglected; most authors seem to have taken the view that numbers were small enough for any effects to be essentially insignificant and, although there were some grounds for this, a clear breakdown would have clarified the position. An analysis of non-responders at 16-years, in terms of data gathered earlier at birth, 7 or 11 years, indicated that some bias would arise in some variables at 16 years due to non-responders (Goldstein, in [6]).

Variables tested by Goldstein which were not significantly (at the 5% level) differently distributed among the four response categories of Table 2.1 at 16 years, compared with the 11-year data are shown in Table 2.2. Variables whose distributions among the four response categories were different at 16 years, but where no significiant differences were found between those with data at 16 years and those without, are shown in Table 2.3. Variables which did indicate a bias, and the percentage bias, are shown in Table 2.4. (Tables taken from Goldstein in [6]).

Because of the amount of data generated by the NCDS project, and the consequent difficulty in taking account of all missing data, especially of the second type, our policy, in line with that of most other users of the data, has been to compare distributions of scores on each variable for the subgroup under investigation with that for the entire population, in each case using every subject for whom scores on that variable are available. This means that the actual children compared will vary from one variable to another. This policy

TABLE 2.2

NON-SIGNIFICANTLY DIFFERENTLY DISTRIBUTED VARIABLES

The following eleven year variables, categorised into dichotomies indicated, were studied but differences were not significant at the five per cent level :

1. Whether mother stayed at school beyond the minimum leaving age
2. Social class (Non Manual, Manual)
3. Social class (III Manual and IV, V)
4. Multiple births (singleton, multiple)
5. Child often or sometimes bored (parental opinion)
6. Time off school (< 1 week in past year)
7. Doctors assessment of vision (any defect)
8. Doctors assessment of hearing (any abnormal loss)
9. Boys pubic hair (stage 1)
10. Girls pubic hair (stage 1)
11. Abnormalities at medical examination (any abnormalities)
12. Any abnormalities of ear, nose, throat, palate, at medical examination
13. Ever had asthma
14. Whether father stayed at school after minimum leaving age
15. Whether parents wanted child to leave school as soon as possible.

TABLE 2.3

SIGNIFICANTLY DIFFERENTLY DISTRIBUTABLE VARIABLES

For the following eleven year and seven year variables, categorised as indicated, significant differences (at the level indicated) were found between the four response categories, but no significant differences were found between those with data at sixteen years and the remainder.

1. Sex**
2. Whether or not in care by seven years*
3. Whether or not had severe reading difficulty at seven years***
4. Whether or not child borrows books from a library at eleven years**
5. Whether or not child had a congenital condition at eleven years*
6. Whether or not there was family financial trouble at eleven years***
7. Whether or not the child had free school meals at eleven years***
8. Tenure at eleven years (owned, rented, tied to occupation)***
9. Position of front door at eleven years (At or below street level, above street level)***
10. Number of home moves between birth and eleven years (0-1, 2-4, 5+)***
11. Whether or not mother satisfied with home, at eleven years*

TABLE 2.4

BIASED VARIABLES IN 16 YEAR DATA DUE TO NON-RESPONDERS

Source	Estimated Bias	Amount of Bias
Special Education at 11 years	Underestimate	4.6%
Illegitimate with data at 7 years	Underestimate	5.7%
Region at 11 years	England over, Scotland Wales over	0.6%; 3.4%; 2.4%
Number of children in household at 11 years	1-2 child under 5 + children over	1.9%; 0.5%
Goes to clubs out of school at 11 years	Overestimate	0.7%
Admitted overnight to hospital at 11 years	Overestimate	0.7%
Household accommodation at 11 years - whole house	- -	2.5%
Crowding at 11 years ≤ 1, ≤ 1.5, > 1.5	Underestimate for ≤ 1.0	0.7%
Antisocial behaviour at school at 11 years	Underestimate	5.4%

is necessary because most children had one or two missing items, so that exclusion of all children with missing data would have resulted in a very small, almost meaningless, group with complete data. Moreover, if we were to retain only those children with data at each stage of the Survey, we would rule out potentially 'different' groups : immigrants, emigrants, highly mobile children, and non-co-operative parents. A "total population" lacking these elements would hardly constitute a representative comparison group. And, although our estimates of prevalence of various sub-groups cannot be perfect, because of the missing data at the time of selection, they will be more accurate than would be the case if we excluded more missing data cases from our calculations.

This policy is justified by the large numbers involved, and the assumptions that missing data is randomly distributed or does not affect the variables in which we are interested. That such assumptions are often, but not always, justified is evidenced by Tables 2.2, 2.3 and 2.4 above. We shall therefore follow previous interpreters of the NCDS data [1][2][6] in utilising all available records for each variable. At the same time, we shall try to ensure that this policy does not lead to distortions when significant differences between subgroups and the general population are being assessed.

The importance of missing data in our analysis stems mainly from two sources : (1) exclusion of children with missing data from appropriate samples; (2) the significance of differences of means between sample groups and the population.

For example, when we choose a sub-sample of children at 11 years using Educational test scores and compare this group with the total study population on a range of variables, the following influences of missing data may occur :

(a) our sub-sample may be too small - i.e. some children for whom the Educational test scores at 11 years are missing may qualify for inclusion. This will only affect our results for a given variable if these "missed out" cases have a different distribution of scores on the given variable from the sub-sample, if there are enough such cases, and if their scores are so different as to radically change the sub-sample distribution. (See (d) below).

(b) Our "total population", i.e. all those subjects for whom scores on a given variable exist, used for comparison, may not be representative of the "missing" population with regard to the distribution of scores on the given variable. This will only be important if the "missing" population is large enough to cause an appreciable redistribution of the given variable, or the difference in distributions is considerable. In the case of subjects for whom we have no data at all, we must admit the possibility of bias in all variables. However, where we have partial data, it would be possible to estimate for some variables, likely bias due to missing values. For example, "wears glasses at 7 years" from "wears glasses at 16 years" or from eye test data at 7, 11 or 16 years. Less directly, it would be possible to estimate e.g. the distribution of children in owner occupied houses, privately rented property and council property from social class, region, etc.

(c) Some children appear in the survey for the first time at 11 years, either because they were immigrants or because they were previously untraced. These children, who may belong to the sub-sample or to the total population, may differ from the other Survey children on some or all of a number of characteristics such as culture, language, mobility, schooling, and ambition. We can estimate the effects of these characteristics on each of the contemporary variables studied, by comparing children with no data before 11 years with the children with data before 11 years. Any differences can then be taken into consideration when comparing the sub-sample with the total population.

(d) In the case of variables relating to a different stage of the Survey, e.g. the PMS, we can compare those children with data at 11 years and those children with no data at 11 years. The latter group may belong to the sub-sample or to the total population. Provided that the distribution of scores on these variables of the "missing at 11" and "present at 11" groups are not so different as to affect the significance of the comparison of the sub-sample with the total population, our main worry with this "missing at 11" group will be that some of them may belong to the sub-sample. (See (a) above).

With these considerations in mind, we carried out our own investigation of missing data, which we now describe.

MISSING DATA INVESTIGATION

Two subgroups of missing subjects, which may vary from the overall population and have implications for the analysis of the remainder were identified. Those who were missing from the PMS Survey, but had educational test data at age 11, the No Birth Data (OBD) Group; and those who were present in the PMS Survey, but were missing educational test data at age 11, the No Total Ability Score (OTA) Group. The two particular variables* used to select these subgroups were "method of delivery" at birth and "total ability score" at age 11. These variables were chosen because : all the children who had a total ability score (TA) at age 11 and whose "method of delivery" was missing from the PMS data, also lacked all the other PMS data; and, all the special subgroups considered in our research were chosen on the basis of their Ability and Achievement Test results at age 11, and these test results all tended to be present or absent together.

This choice resulted in the following numbers of children being identified for these subgroups :

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* A list of variables used in the study is given in Appendix 2.1.

TABLE 2.5

CONSTITUTION OF "MISSING DATA" SUBGROUPS

TYPE OF DATA	OTA GROUP Birth Data but no TA at 11	OBD GROUP TA at 11 but no Birth Data
PMS - Birth Data	*3969 cases	* 0 cases
Educ. Quest. at 7	*2078 "	*423 "
Parental Quest. at 7	*1970 "	*393 "
Medical Quest. at 7	*1870 "	*377 "
B.S.A.G. at 7	*2055 "	*419 "
Educ. Quest. at 11	107 "	*692 "
Parental Quest. at 11	894 "	*597 "
Medical Quest. at 11	759 "	*555 "
Educ. Quest. at 16	1420 "	470 "
Parental Quest. at 16	1261 "	417 "
Medical Quest. at 16	1280 "	471 "
Child Quest. at 16	1359 "	439 "

Since our later investigations will be made on the basis of achievement at 11, and will concern variables at birth, 7 and 11 years primarily, and Goldstein's analysis of missing values was not made until age 16, we decided to look at differences between the groups in Table 2.5 who might have had an effect on our study (marked *) and the total population, on each relevant variable.

Table 2.6 shows how these groups may have arisen and how representative (numerically) they may be of all missing cases. (Data taken from various publications, mainly [6] and [2]).

TABLE 2.6

MISSING DATA AT EACH STAGE OF THE NCDS

STAGE	TOTAL WITH DATA	NO DATA OR NOT TRACED	REFUSED TO CO-OPERATE	DIED OR EMIGRATED	NEW CASES	TOTAL IN SURVEY
Birth	17,419	314	-	-	-	17,733
Age 7	15,406	1394	83	1235	540	18,118
Age 11	15,307	702	826	1530	296	18,365
Age 16	14,761	1009	1141	1667		18,578

STATISTICAL COMPARISONS

I. OTA GROUP

Those with Birth Data* All variables were compared by categories using chi-squared tests.

Two variables were significant ($p < .01$) : "gestation period" all but one of those babies < 206 days were in the OTA group; and "method of delivery" where in three categories the OTA group contained the only cases. Moreover, the OTA group had relatively more abnormal deliveries in every category except "caesarian in labour" and "spontaneous-vertex OP".

Although no other variables were significant, there was a trend for the OTA group to contain more "at risk" cases, as identified by the PMS Survey - i.e. there were more raised blood pressure and proteinuria cases, especially severe cases, more foetal distress, more very small and very large babies by birthweight, more bleeding in pregnancy in every category, more very young mothers, more very short or very tall mothers, and more boy babies.

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* A list of variables used in the study is given in Appendix 2.1.

Those with 7 year data. All variables, except test score results, were compared by categories using chi-square tests. For tests, comparisons were made using t-tests.

Significant variables were only found amongst the t-test results; these were the average scores on "Problem Arithmetic Test", "Southgate Reading Test" and "Copying Designs" test, all of which were lower for the OTA group ($\rho < .01$).

Although no other comparisons of variables reached significance, we noted that the OTA group was generally rated "worse" than the population on measures of achievement, co-ordination, disabilities, behaviour, school attendance, and natural parenting, but "better" than the population on pre-school experience, and social class. Detailed comparisons are in Appendix 2.2; in particular, Tables 2.2.1 and 2.2.2 show comparisons of both the OBA and OTA groups with the total population for Social Class (at age 7) and for certain laterality variables, respectively, showing a large measure of similarity between groups.

II. OBD GROUP

The findings for this group at age 7 and at age 11 are very similar, in spite of the change in constitution, so we shall consider the two ages together.

The following variables were significantly differently distributed in the OBD group, compared with the total population (chi-square tests, except for test scores, where t-tests were used) :

Family moves from birth to 7, more in OBD group;
Number of schools attended to 7 and 11, more in OBD group;
Father stayed on at school, more in OBD group;
Child attended private nursery, more in OBD group;
Care by natural father, fewer in OBD group;
Mother English-speaking (age 7), fewer in OBD group;
English spoken at home (age 11), fewer in OBD group;
Imperfect grasp of English (age 11), more in OBD group;

All ability and achievement tests at age 11 were significant (.01; Maths .02; Copying Designs .05) when average scores were compared by the t-test, with the OBD group worst, but comparisons of test scores by category groupings using chi-squared were not significant, nor were any achievement variables at 7 years.

More details of the comparisons are given in Appendix 2.2, where it will be seen that among the variables which did not reach significance, there was also a clear pattern, supporting that of the significant variables.

Implications of Missing Data

The influence of the OTA group on our analyses will be seen primarily in the birth- and 7-year data. Because of their lack of ability test scores at 11 years, the OTA group will never contribute to our special subgroups, but will be part of the "total population" with which these subgroups are compared. Our "missing data" investigation therefore suggests that we shall over-estimate the prevalence of abnormalities in pregnancy and at birth among the population of surviving 11 year-olds, and that we shall slightly underestimate their average scores on the 7-year achievement tests.

Also, some of the OTA group may actually belong to special subgroups, but, because of missing test scores, be misplaced into the "total population" for comparison purposes. This latter point also implies that the sizes of the special subgroups are almost certainly under-estimates, and therefore so is the incidence of abnormalities of birth and pregnancy in such subgroups, while their average seven-year achievement test scores may be slight over-estimates.

The OBD group will supply members to our special subgroups and also contribute to the "total population". Since there are fewer than 700 members of the OBD group, we expect that their influence on the "total population" (17,000+ members) will be very slight, and have little effect on our analyses. Where our investigations involve this group, these findings will be borne in mind.

The contribution of the OBD group to special subgroups will also be very small in practice, although theoretically it could be large enough to affect the characteristics of such subgroups. For example, the number of OBD group members in the main special subgroup dealt with in our analysis is 4, out of 142. Of these 4, 3 came into the survey at age 7 and one at age 11. Three of the OBD significant variables related to spoken English, and for these 4 dual group members we found that one was bilingual at home, two spoke English at home, and the other had no PQ or MQ at age 11 but at age 7 had an English mother.

Thus, in general, the small numbers involved suggest that the OBD group will have little effect on our special subgroup - population comparisons, even for those variables for which the OBD differs significantly from the population.

From this investigation of missing data up to the 11-years Survey, it seems that (for the purposes of our investigation) missing data is not a crucial factor in the data up to 11 years. This conclusion is similar to that of others who have used the NCDS data, but although many studies have assumed that missing data would be relatively unimportant, few have really looked closely at the data to confirm this. With the present information at hand we will be able to modify conclusions where appropriate, but feel able to proceed more confidently with the analysis. Where there are effects, the largest will be to over-estimate the prevalence of abnormalities in pregnancy and birth data in the total population,* and to slightly under-estimate their average achievement test scores at age 7.

We have tried to give a description of the NCDS data, and missing data, in sufficient detail to illustrate its potential value in any enquiry such as ours, and also some of its technical limitations. We now turn to its general value and relationships to the present research.

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* That is, we shall under-estimate the significance of these variables in our SMU subgroups (Chapter III) in comparison with the total population.

III OUR USE OF THE NCDS DATA AND SOME LIMITATIONS

(1) The NCDS data is unique in its scope; not only were over 98% of all possible subjects included in the PMS stage (over 87% at 7 years, and over 90% at 11 years), but these children were followed up educationally, socially and emotionally for over 16 years. This means that not only can we look at cross-sectional data and averages, but also at progress of individuals over time. Moreover, antecedent variables are built in to the data, very few were gathered retrospectively.

(2) The main snag for some researchers is that the Survey was confined to children born in one specific week, so that fluctuations in variables depending on time of year of birth (e.g. effect of birthdate on education) cannot be investigated. On the other hand, some babies were born early (up to 8 weeks for survivors) and some late (up to 3 or 4 weeks), some children started school early and others late, and investigations of the influence of these factors on later variables can be made without the added complication of month of birth.

(3) The data was collected using multiple-choice, pre-coded items on sets of three or four questionnaires at each age. Although this would tend to preclude what could be interesting variations such as personal impressions, modified answers, etc., it has potentially greater uniformity, which is important when many different people are collecting the data, and may lead to more accuracy.

(4) The greatest defect of the data for our purposes is that the variables used were those thought most relevant at the time to the various contemporary aims of the NCDS enquiry, which did not envisage enquiries such as ours. To the credit of the authors of the NCDS, thoughts on variables relevant to the declared aims of the Study have not changed radically over the years, and are well backed up by experimental results in previous literature. However, our main concern - under-achievement - seems to have been omitted both in the concepts of the Study and in the vast literature based on the data generated. Thus, although separate measures of 'Ability' (Verbal Ability and Non-Verbal Ability) and 'Achievement' (Maths, Reading Comprehension) were obtained at age 11, discrepancies have not been researched, and 'Ability' has seldom been used as an explanatory variable. It may be that the researchers felt that 'Ability' is only ascertained through 'Achievement' or that Achievement tests so reflect Ability as to make them almost interchangeable, but this is never expressed. On the other hand, their gathering of "Attainment" data at ages 7, 11 and 16, but "Ability" data at age 11 only, would lead one to suppose that they considered that "Ability" can be ascertained, and if measured at 11, could be used as a fairly stable indication of ability over the remaining school years. This hypothesis, as well as others concerning the constancy, change and age of onset of underachievement could have been investigated more fully if "Ability" tests had been included at 7 and 16. This omission is quite surprising in view of the fact that the battery was devised for research purposes. As it is, we are left with only one set of Ability measures (at age 11) so that we have

to assume that it is fairly stable over the school years and has some validity as an independent variable.

(5) Ideally, we would have like a measure of short-term memory at each age. It is easy to see why this was not incorporated, since it would have lengthened test sessions, involved one-to-one testing, and its relevance to various areas of academic functioning was less evident then than it is today.

(6) Less obvious is the omission of laterality tests at age 16; such tests were used at ages 7 and 11, and, although lateralities were fairly stable over that period, enough changes were recorded to make the question of stability from ages 11 to 16 worthwhile (see Chapter VII)
However, the measures which were included were sufficient to enable us to both form hypotheses, and to test hypotheses generated elsewhere. Moreover, for a preliminary enquiry such as ours, a large number of subjects with adequate, if less than optimum, data variables is more appropriate in may respects than a restricted sample with a comprehensive range of variables.

(7) Although piloting of the different stages was not always as thorough as some participants would have liked [2], each instrument used at every stage of the Survey was piloted (and standardised, where necessary). Reliabilities of attainment tests and ability tests were adequate (see pages 64 and 65). One curious omission from all accounts of the project and from the National Children's Bureau (personal communication) is

validity data for the separate 'Verbal' and 'Non-Verbal' scales of the ability test, although scores on these scales are freely referred to as 'Verbal Ability' and 'Nonverbal Ability' throughout the literature. This Ability test was constructed by the NFER and was also used in a previous major survey [8]. Validation and comparison with, e.g. the Wechsler scales, would greatly strengthen our case in Chapter VIII; as it is we can only say that the scales have face validity, and that, although not documented, their initial validation is assumed to have had some concurrent validation in the construction by the NFER (personal communication).

(8) Another potential drawback to the data from our point of view is the use of so many rating scales in all types of questionnaire. For some variables this is not very serious, and some can be checked against other measures (e.g. teachers' ratings of Maths ability should bear some resemblance to the Maths test scores; mothers' ratings of settling down at school should compare favourably with teachers' ratings). But when looked at in terms of individual cases, there are likely to be considerable variations between raters. The limited experience of the rater, regional and even neighbourhood variations, and the rater's own personal background might influence their ratings of behaviour and even of speech. Our concern with this issue was, however, somewhat alleviated by making cross-checks in certain cases in which we have been interested. These did, for example, show a fair agreement between mothers' ratings of behaviour and those of teachers, but there were enough disagreements to make us

remain wary of relying on single ratings of particular individuals.

To sum up, although the drawbacks of the NCDS data are sometimes inconvenient, and often call for caution in interpretation, they are far outweighed by the advantages of the data for a preliminary investigation such as ours.

We now present a brief selection of results from published work based on the NCDS data.

We shall summarise results which are relevant to our investigation, and in some cases have also included more detailed descriptions of other findings in an Appendix (2.3).

IV RESULTS FROM THE NCDS DATA - A SELECTION FROM THE LITERATURE

We have included most of the results of the PMS Survey in view of the theory put forward by Kawi and Pasamanick [9][10] to explain some cases of dyslexia. Kawi and Pasamanick studied a series of 205 reading-retarded children, finding that for 16.6% there had been complications during pregnancy (e.g. pre-eclampsia, bleeding, hypertension) compared to only 1.5% for a control group of normal readers. This led them to propose that factors that caused severe brain damage might also lead to abortion, still-birth and neo-natal death; while lesser degrees of damage at or prior to birth could result in cerebral palsy, epilepsy, and behaviour disorders; whilst the mildest degrees of damage are followed by faulty speech and congenital dyslexia. "It would appear that a certain proportion of reading disorders might be added to the continuum of reproductive casualty". Although such a view ignores the proven capacity of the infant brain to recover to a remarkable extent from much more severe brain insults (e.g. hemispherectomy), it does explain the similarities between developmental and acquired cases and their relative severities; we certainly cannot dismiss it out of hand. This theory would imply that factors which are important in perinatal mortality, may also be important in cases of learning-disability.

In Perinatal Mortality [1] only singleton births were considered, in general. Mortality ratios were calculated for each variable studied by comparing the incidence of that variable in the perinatal deaths with its incidence among the babies from the control week who survived. Increased mortality ratios were found to be correlated with a large number of variables including : region, unbooked deliveries, mother's age, parity, social class (the effects of the latter three variables being independent of each other), past obstetric history, prenatal care, toxaemia, bleeding in pregnancy, gestation period, birthweight, length of labour, and method of delivery.

Necropsy findings indicated that the primary causes of death among stillbirths were anoxia and/or cerebral birth trauma (57.7%) and congenital malformation (17.5%). Among early neonatal deaths these causes accounted for only 19.6% and 21.6% respectively, while pneumonia (13.3%), hyaline membrane (15%) and haemorrhages (12.3%) were frequent. In late neonatal deaths congenital malformations

(45.3%) and infection (36.1%) were dominant conditions.

These latter findings give weak support to the idea that learning disabilities may result from some less severe cases of congenital malformation of certain brain structures.

Two books have been devoted to findings in the 7-year follow-up [2][7]. As we have already mentioned, no attention has been paid to under-achievement, its correlates, or predictors. As Rutter and Yule [11] have shown for Reading, and as we believe to be the case for Mathematics, factors influencing under-achievement are likely to be quite different from factors influencing lack of achievement.

Not surprisingly, in view of past studies, the variables with the largest effect on attainment in general were social class, family size and overcrowding. Also predictable from other studies, was the finding that more boys than girls were thought to be in need of special help, and more boys than girls were non-readers at age 7. But only slightly more boys than girls (3.8% to 3.3%) showed virtually no understanding at all of number work [2]. We shall see that these latter proportions are quite different in the case of under-achievement; as are the significant variables associated with it. Moreover, there was a strong association between behaviour and lack of achievement as measured by the Bristol Social Adjustment Guides (score 20 or more considered 'maladjusted') and scores on the Southgate Reading Test (score 3 or less considered 'non-reader', score 12 or less considered 'backward reader') with 40% of 'backward readers' being 'maladjusted' and 54% of 'non-readers' being 'maladjusted' compared with 10% of non-backward readers [2].

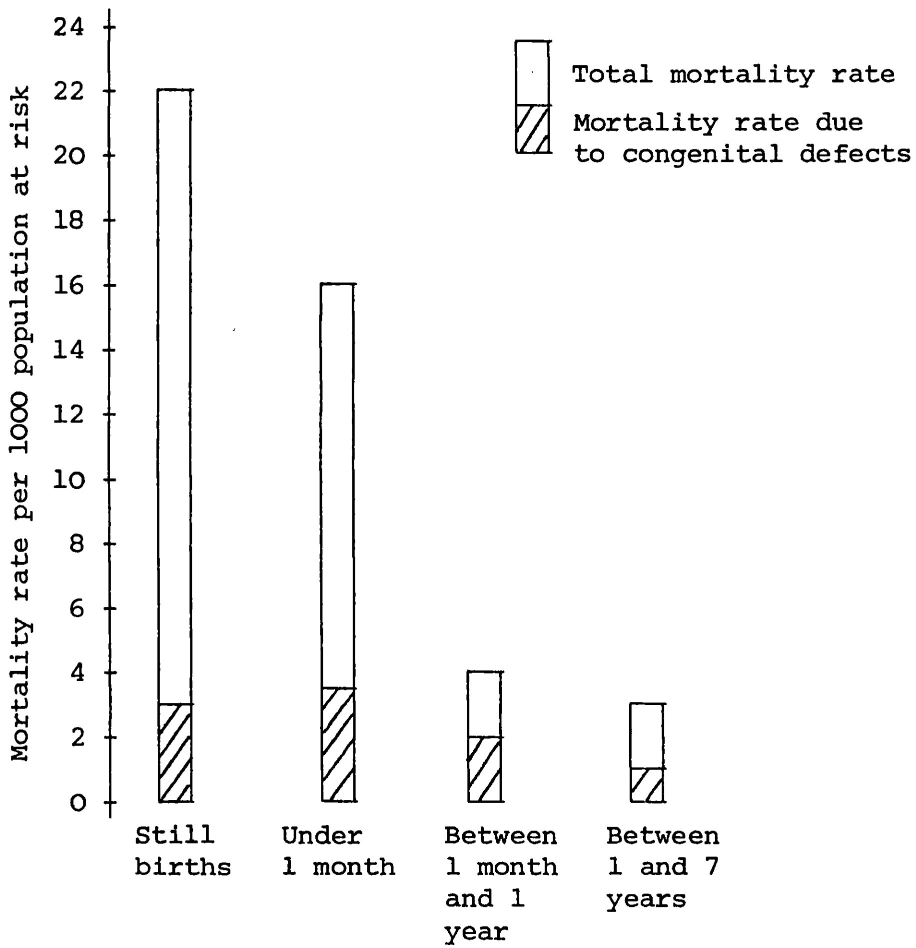
Considering the theory of Kawi and Pasamanick, it is interesting to look at causes of death between 1 month and 7 years in Table 2.7 (taken from [2]), and at serious defects (excluding vision, hearing and speech) in the cohort at 7 years in Table 2.8 (taken from [2]). Supporting their idea that slightly less severe damage would lead to various degrees of mental impairment, is the finding that of 34 severely subnormal children, 29 had associated defects; while of 186 formally ascertained for special educational treatment, nearly $2/3$ had defects. Of those children in normal schools whose teachers thought they needed special schooling, about $1/5$ had defects.

The factors most predictive of sensory and physical defects and of severe subnormality were birth order, method of delivery, and condition of baby in first week (but not all PMS factors were tested); social class and birthweight-for-gestation did not improve prediction further. Of those tested, the factors more predictive of less severe mental retardation were birth order, social class, birthweight-for-gestation and method of delivery; condition of baby in first week did not improve the prediction. Table 2.9 (taken from [2]), shows how successful these predictors were for the NCDS cohort.

That some other factors may be involved, and different factors affect different outcome variables, is suggested by the investigation of the relationship between PMS factors and the outcome variables

TABLE 2.7

TOTAL MORTALITY RATES AND
DEATHS DUE TO CONGENITAL DEFECTS



NUMBER AND CAUSES OF DEATHS OCCURRING
BETWEEN FOUR WEEKS AND SEVEN YEARS

Cause of death	Number of Children Boys	Girls	All
Congenital defect	21	29	50
Cerebral palsy/birth injury	4	3	7
Intussusception	2	0	2
Malignancy	5	5*	10*
Infection	31	21	52
Asphyxia/inhaled vomit	3	2	5
Accident	-	3	3
All	74	69	143

* One mongol is included here and in the category of congenital defect but only counted once in the total.

TABLE 2.9

NUMBERS AND INCIDENCE OF SERIOUS DEFECTS WHICH WERE CONGENITAL OR AROSE AT OR SHORTLY AFTER BIRTH
(EXCLUDING DEFECTS OF THE SPECIAL SENSES)

Congenital disorder	Stillbirths and deaths before 4 wks	Deaths 4 wks to 7 years	Number in NCDS	Alive at 7 years Corrected number †	Incidence per 1000	All † Corrected number †	All † Incidence per 1000
Anencephalus	32	-	-	-	-	32	1.8
Spina Bifida and/or Hydrocephalus	42	14	15	18‡	1.1	74	4.2
Heart or blood vessels	36	19	56	60	3.6	115	6.6
Cleft palate	1	-	23	25	1.5	26	1.5
Club feet	21	-	48	51	3.1	72	4.1
Dislocated hips	1	-	17	18	1.1	19	1.1
Other bones or joints	9	1	24	26	1.6	36	2.1
Other malformations	115	3	34	37	2.2	155	8.9
Mongolism	14	7	11	14‡	0.8	35	2.0
Other 'severe subnormality'	-	-	23	25	1.5	25	1.4
Cerebral palsy	-	5	36	39	2.3	44	2.5
Cancer, leukaemia or other tumour	-	10	4	4	0.2	14	0.8
Other congenital disorders	1	9	29	31	1.9	41	2.3
Total children (some have more than one defect)	144	67	398	426	25.6	637	36.6
No. in cohort	669	143	15496*	16606		17418	

* Includes 643 children not matched with perinatal cohort.

† Each total incidence has been corrected to allow for defects estimated to be present in untraced children.

‡ For Spina Bifida and mongolism the actual number amongst the untraced children is known, because they were diagnosed at birth.

TABLE 2.9

OPTIMAL GROUPINGS FOR PREDICTION AND ENTRY ONTO 'AT RISK' REGISTER

	Severe physical or mental, or multiple handicap	Educational backwardness requiring special schooling
Prevalence per cent	1.4	2.3
Criteria for entry into the register	1. High birthrank (fifth or later) or : 2. Abnormal delivery (breech, face, internal version or by untrained person) or : 3. Abnormal signs or serious illness in first week (convulsions, cyanotic attacks, cerebral signs, hypothermia, serum bilirubin 15 mgm per 100 cc or more, Rh incomparibility or other serious illness).	1. Illegitimate birth or father unskilled worker or : 2. High birth rank (fifth or later) or : 3. Abnormal delivery (breech, face, internal version or by untrained person) or : 4. Abnormal birthweight or gestation (a) 5½lb (2,500 g) or less, or born before 37 weeks. (b) Born 43 weeks or later.
Children on register as percentage of all live births	13.2	24.7
Percentage of handicapped children included in register	25.3	53.6

'recognised handicap' (i.e. teachers thought special schooling was needed), 'clumsiness' (teachers rated as 'certainly') and 'copying designs' test score (score 0 to 4). The relevance of the latter two variables in the present context is that 'clumsiness' is often taken as a 'soft' neurological sign of 'minimal brain damage', while failure to copy simple designs may indicate a motor deficit, a perceptual deficit, or a perceptuo-motor deficit. It was found that short gestation and long gestation, allowing for social class and birth order, both carried increased risk of educational backwardness (a recognised handicap) and clumsiness at age 7. Short gestation and light-for-gestation variables were related to poor copying designs scores, allowing for social class and birth order. Light-for-gestation and heavy-for-gestation babies were also at risk for educational backwardness at age 7. However, the only important association between the three outcome variables and certain birth factors (severe pre-eclampsia, bleeding in pregnancy, foetal distress, prolonged labour and abnormal method of delivery) was between foetal distress and clumsiness. The proportion of handicapped children and those thought to be in need of special schooling was increased amongst mothers who had not been attended by a trained person in labour.

As we shall see later, some of the variables mentioned in this brief look at the NCDS literature are relevant to the special sub-groups in which we shall be interested.

More results from the NCDS literature are presented in Appendix 2.3; some of these results are not directly related to our investigation, but have relevance insofar as they demonstrate the differences between our special subgroups and other groups of low-achieving children of the general population.

In Chapter III we shall select our main special subgroup of mathematical under-achievers from the NCDS data, examine variables correlated with under-achievement specific to mathematics, and look for commonalities among groups of specific mathematical under-achievers.

APPENDIX 2.1.

VARIABLES OF THE NCDS CHOSEN FOR OUR INVESTIGATION

VARIABLE NUMBER		DESCRIPTION
1		Child's identity number in NCDS
EDUCATIONAL QUESTIONNAIRE AT AGE 7.		
2		Category of school.
3		Not LEA school.
4		Age when phonics begun.
5		" " sums "
6		Special teaching unit.
7		Help with backwardness.
8	TR	Child would benefit from special school.
9	TR	Child will need special school or help in next 2 yrs.
10		Referral to agency for difficulties in school.
11		Difficulties which have now disappeared.
12		Parent's initiative to discuss child.
13		Teacher's " " " "
14	TR	Mother's interest in child's education.
15	TR	Father's " " " "
16	TR	Settling down after starting school.
17		Number of pupils in child's class.
18		Formation of child's class
19		Possible ½ day attendances in last Autumn term.
20		Number of ½ day absences " " " "
21	TR	Oral ability of child.
22	TR	Child's awareness of world around.
23	TR	Child's reading ability.
24	TR	Child's creativity.
25	TR	Child's ability at number work.
26		Child's reading standard.
27	TR	Poor control of hands.
28	TR	Poor physical coordination.

29	TR	Clumsy.
30	TR	Always moving about.
31	TR	Difficult to understand because of poor speech.
32		Problem Arithmetic Test score.
33		Southgate Group Reading Test score.

PARENT'S QUESTIONNAIRE AT AGE 7.

34		Family moves since child's birth.
35		Child's position (chronolog) among children of household.
36		Child cared for by mother or mother substitute.
37		" " " " father " father "
38		Child attended LEA nursery or class.
39		" " private " " "
40		" " LEA day nursery.
41		Other pre-school experience.
42		Child's age on starting school part-time.
43		" " " " " full-time.
44		Number of schools attended since age 5.
45	MR	Settling down on starting school.
46	MR	Happy at present school.
47		Parents want child to stay on at secondary school.
48	MR	Child awkward or clumsy tying a bow.
49	MR	Child's activity level.
50	MR	Child has difficulty in settling to anything.
51	MR	Child worries about many things.
52		Child's school attendance.
53		Father's social class.
54		Father stayed on at school.
55		Child walked alone by 1½ years.
56		" talked by 2 years.
57		Child attended Child Guidance Clinic.
58		Child had fit or convulsion in first year.
59		" " " " " after first year.
60		Child has frequent headaches or migraine.
61		Child has had concussion or head injury.
62		Glasses have been prescribed for the child.

63		Total number of births to mother.
64		Child's position in birth order.
65		Mental illness or neurosis in family.
66		Mental subnormality in family.
67		Mother English-speaking.

MEDICAL QUESTIONNAIRE AT AGE 7.

68		Child's height without shoes to nearest cm.
69		" weight in underclothes " lb.
70		" head circumference " " 0.5 inch.
71		" hand laterality (draw and throw).
72		" foot " (kick and hop).
73		" eye " (sight thro' tube and card).
74	DR	Doctor's assessment of child's vision.
75		Number of mispronounced words in test sentences.
76		Stammer in child's speech.
77	DR	Assessment of intelligibility of speech.
78	DR	Doctor's assessment of child's hearing.
79	DR	Child in need of special educational treatment.
80		" " " " " " "
81		" " " " " " "
82		Child receiving spec. ed. treatment in spec. school.
83		Child in special teaching unit.
84	DR	Child likely to need a special school.
85	DR	Child's educational needs.
86	DR	Child has general motor handicap.
87	DR	Child suffering from mental retardation.
88	DR	" " " emotional maladjustment.
89	DR	" " " epilepsy.
90	DR	" " " other CNS condition.
91	DR	Child's size tall/short.
92	DR	" " fat/thin.

THE BRISTOL SOCIAL ADJUSTMENT GUIDES AT AGE 7.

93	TR	Unforthcomingness syndrome.
94		Withdrawal syndrome.
95		Depression "

96		Anxiety syndrome.
97	TR	Hostility to adults syndrome.
98	TR	Writing off adults and their standards syndrome.
99	TR	Anxiety for acceptance by children "
100	TR	Hostility to children syndrome.
101	TR	Restlessness syndrome.
102	TR	Inconsequential behaviour syndrome.
103	TR	Miscellaneous symptoms.
104	TR	" nervous symptoms.
105		Total score for all syndromes.

EDUCATIONAL (AGE 7)

106	Copying Designs Test score.
107	Child's attendance.
108	" "
109	" "
110	" "

PERINATAL MORTALITY SURVEY DATA.

111	Gestation Period in Days.
112	Mother's height to nearest inch.
113	Birthweight forgestational age for sex S.D. groups.
114	All bleeding in pregnancy and before delivery.
115	Method of delivery.
116	Foetal distress.
117	Mother stayed on at school.
118	Raised blood pressure and proteinuria.
119	Mother's age.
120	Sex of child.

EDUCATIONAL QUESTIONNAIRE AGE 11.

121		Type of school.
122		Non-LEA school.
123		Help for educational or mental backwardness.
124		" " " " " superiority.
125		" " behaviour difficulties.
126		" " physical or sensory disability.
127	TR	Child would benefit from special school.

128		No. of possible ½ day attendances.
129		No. of ½ day absences.
130	TR	Child's general knowledge.
131	TR	" number work.
132		" use of books.
133	TR	" oral ability.
134	TR	Poor control of hands.
135	TR	" physical coordination.
136	TR	Child hardly ever still.
137	TR	" difficult to understand because of poor speech.
138	TR	Child has imperfect grasp of English.
139	TR	" " outstanding ability in some area.
140		General ability test - Verbal ability score.
141		" " " Non-verbal ability score.
142		General ability test - Total ability score.
143		Reading comprehension test score.
144		Mathematics test score.
145		Copying Designs test score.

BRISTOL SOCIAL ADJUSTMENT GUIDES - AGE 11.

146	TR	Unforthcomingness syndrome.
147	TR	Withdrawal syndrome.
148	TR	Depression syndrome.
149	TR	Anxiety for acceptance by adults syndrome.
150	TR	Hostility to adults syndrome.
151	TR	Writing off adults syndrome.
152	TR	Anxiety for acceptance by children syndrome.
153	TR	Hostility to children syndrome.
154	TR	Restlessness syndrome.
155	TR	Inconsequential behaviour syndrome.
156	TR	Miscellaneous symptoms.
157	TR	" nervous symptoms.
158		Total syndrome scores.
159	TR	Miscellaneous symptoms - truancy.
160	TR	" " - destructiveness.
161	TR	" " - outsider.

162	TR	Miscellaneous symptoms
163	TR	Attendance syndromes.
164	TR	" "
165	TR	" "
166	TR	" "
167	TR	Physical syndromes short/tall.
168	TR	" " fat/thin.

PARENTAL QUESTIONNAIRE AGE 11.

169		Number of schools attended since age 5.
170		Mother's most recent job.
171		Family contact with Mental Health. } etc.
172		" " " Child Guidance Clinic. }
173		Family contact with Special Education Dept. } etc.
174		" " " school welfare. }
175	MR	Child's sight.
176	MR	Child's hearing.
177	MR	Any speech difficulty.
178	MR	" " "
179		Child has had speech therapy.
180	MR	Child's handedness.
181		Hand used by child for writing.
182		Any accident causing unconsciousness.
183		" " " "
184		Any epileptic attacks, convulsions, faints, etc.
185		" " " " " "
186		" " " " " "
187		Any recurrent headaches or migraine.
188		Is English usual language used at home.

MEDICAL QUESTIONNAIRE AGE 11.

189		Child needs special educational treatment.
190		Reasons for " " "
191		" " " " "
192		" " " " "
193		Child has condition affecting neurological function.
194		Any psychological or psychiatric opinion or treatment.

195		Any congenital condition or handicap.
196		Child's height in inches, without shoes.
197		Child's weight in lbs. in underclothes.
198	DR	Neurological, muscular, or orthopaedic disorder.
199	DR	" " " " "
200	DR	" " " " "
201		Number of words mispronounced in speech test.
202	DR	Defect of articulation.
203	DR	" " "
204	DR	Hearing examination assessment.
205	DR	Visual examination "
206	DR	" " "
207	DR	" " "
208	DR	" " "
209	DR	" " "
210		Hand used to throw ball.
211		" " " " "
212		Foot " " kick "
213		" " " " "
214		Eye used for sighting through tube.
215		" " " " " "
216		Unsteadiness walking backwards on a line.
217		" standing on R foot for 15 secs.
218		" " " L " " " "
219		" " heel to toe for 15 secs.
220		Number of catches of ball with R hand out of 10.
221		" " " " " " L " " " "
222		" " squares marked with R hand in 1 min.
223		" " " " " L " " " "
224		Time to pick up 20 matches with R hand.
225		" " " " " " " L "

EDUCATIONAL (AGE 16)

226		Academic Motivation Scale Score.
227		" " " "

MEDICAL QUESTIONNAIRE (AGE 16)

228		Decision by LEA regarding special educational treatment.

229		Category of handicap.
230		" " "
231		" " "
232		IQ score if recorded.
233		Hospital admission in last year - diagnosis.
234		Casualty department in last year - diagnosis.
235		Psychologist or psychiatrist seen - reason.
236		Are glasses prescribed at present.
237	DR	Hearing assessment.
238		Speech test, number of mis-pronounciations.
239	DR	Intelligibility of speech.
240		Height in cms. without shoes.
241		Weight in kgs. in underclothes.
242	DR	Steadiness standing heel to toe for 15 secs.
243	DR	" hopping on Left foot.
244	DR	" " " Right "
245		Number of catches with Right hand out of 10.
246		" " " " Left " " " "
247	DR	Summary of child's coordination.
248	DR	Child has general motor handicap.
249	DR	Child suffers from mental retardation.
250	DR	Child has emotional/behavioural problem.
251	DR	Child has eye condition.
252	DR	" " hearing defect.
253	DR	" " speech defect.

EDUCATIONAL QUESTIONNAIRE AGE 16.

254		Type of school attended.
255		Whether co-ed. school.
256		% age of 15 year old boys in school doing GCE &CSE.
257		% " " " " " girls " " " " " "
258	TR	Ability range of child's class for English.
259	TR	" " " " " " "
260	TR	Can child read well enough for everyday.
261	TR	Ability range of child's class for Maths.
262	TR	" " " " " " "

263	TR	Can child do everyday calculations.
264	TR	Child's Mathematical ability.
265	TR	" English ability.
266	TR	" Modern Languages ability.
267	TR	" Science "
268	TR	" Practical subjects "
269	TR	" Social subjects "
270		Help for educational or mental backwardness.
271		" " " " " superiority.
272		" " behaviour difficulties.
273		" " physical or sensory disabilities.
274		Number of ½ days absent Autumn 1973.
275		" " " " " " 1972.
276	TR	In past 12 months has child showed restlessness.
277	TR	" " " " " " " truancy.
278	TR	" " " " " " destroyed property.
279	TR	" " " " " " had fights and quarrels.
280	TR	" " " " " " not been liked by other children.
281	TR	In last year has child worried about many things.
282	TR	" " " " " been on own - solitary.
283	TR	" " " " " " irritable/touchy.
284	TR	" " " " " " miserable/tearful.
285	TR	" " " " " " absent for trivial reasons.
286	TR	" " " " " " unresponsive/inert/apathetic.
287	TR	" " " " " " resentful/aggressive when corrected.
288	TR	" " " " " bullied other children.
289	TR	Is child cautious - impulsive.
290	TR	" " flexible - rigid.
291	TR	" " lazy - hardworking.

PARENTAL QUESTIONNAIRE AGE 16.

292		Was child's birth single or multiple.
293		If parents dissatisfied with child's present school - reasons.

294		If parents dissatisfied with child's present school - reasons.
295		" " " " " "
296	MR	Parents and child argue over homework.
297	MR	Child has speech difficulty other than stutter or stammer.
298		Has child had injury requiring hospital or casualty dept. - most recent.
299		" " " " " " "
300		" " " " " " "
301		" " " " " " "
302		Has child ever had fits or convulsions etc.
303		" " had migraine/recurrent headaches in last year.
304		Has child had specialist opinion for emotional/ behavioural problems.
305		" " " " " " "
306		" " " " " " "
307		" " " " " " "

CHILD QUESTIONNAIRE AGE 16.

308	CR	With which hand does child write best.
309	CR	Child's rating of Maths. ability.
310	CR	" " " English "
311	CR	" " " Science "
312	CR	" " " Art "
313	CR	" " " Music "
314	CR	" " " Practical subjects ability.
315	CR	" " " Sports and Games "
316		Reading Comprehension test score.
317		Maths. Test score.

TR = Teacher Rating　　MR = Mother's Rating
DR = Doctor's Rating　　CR = Child's Rating.

These 317 variables were chosen from over 2500 available in the NCDs data.

APPENDIX 2.2

FURTHER DETAILS OF "MISSING DATA" GROUPS COMPARED WITH THE TOTAL POPULATION

The OTA Group Slightly more mothers had stayed on at school. Worse teacher ratings on all achievement variables at age 7.

Worse ratings on measures of speech, coordination, clumsiness, over activity, difficulties in behaviour, backwardness, developmental milestones of walking and talking, and school attendance. Worse ratings on most of the individual scales of the Bristol Social Adjustment Guides at age 7 ; numerically their average scores on most of these scales were significantly higher, but were caused by a few extremes, as shown by the non-significant differences between scores when these were categorized and the chi-square test used.

More of the OTA group had physical disabilities at age 7 :- general motor handicap, CNS conditions, epilepsy, partial sight. There were more extremes of size :- very light, very heavy, very fat, large head circumference, small head circumference.

These children had typically experienced more moves since birth and more had attended more than one school.

Twice the population percentage were adopted, slightly fewer were cared for by their natural mothers, and fewer by their natural fathers. More were the only births to their mothers, and more were very low in birth order ($\geq$ eighth).

They were slightly more likely to have attended a private nursery or a local authority day nursery, to have attended school part-time at first, and to belong to Social Class groups I and II.

The OBD Group Categorized syndrome scores and average total scores on the Bristol Social Adjustment Guides were not significantly different from those of the total population at 7 or 11, but average scores on some individual syndrome scales did teach significance, with the OBD group scoring worse on "hostile to adults" at both 7 and 11, "restlessness" at 7, "inconsequential behaviour" at 7, "hostile to children" at 11, and "babyish" at 11. In general, there were fewer extremes in the OBD group.

Among other variables which did not reach significance more children were rated, and scored, very high or below average on achievement variables ; more attended private schools (twice as many as the general population) ; more were receiving help in ordinary schools but fewer in special schools, more were 'slightly' mentally retarded, emotionally maladjusted, had non-handicapping epilepsy, and more had poor coordination. There were slightly more cases of fits, frequent headaches, concussion or head injury, poor eyesight, small children, light children, and small head circumferences. Fewer were first or second children.

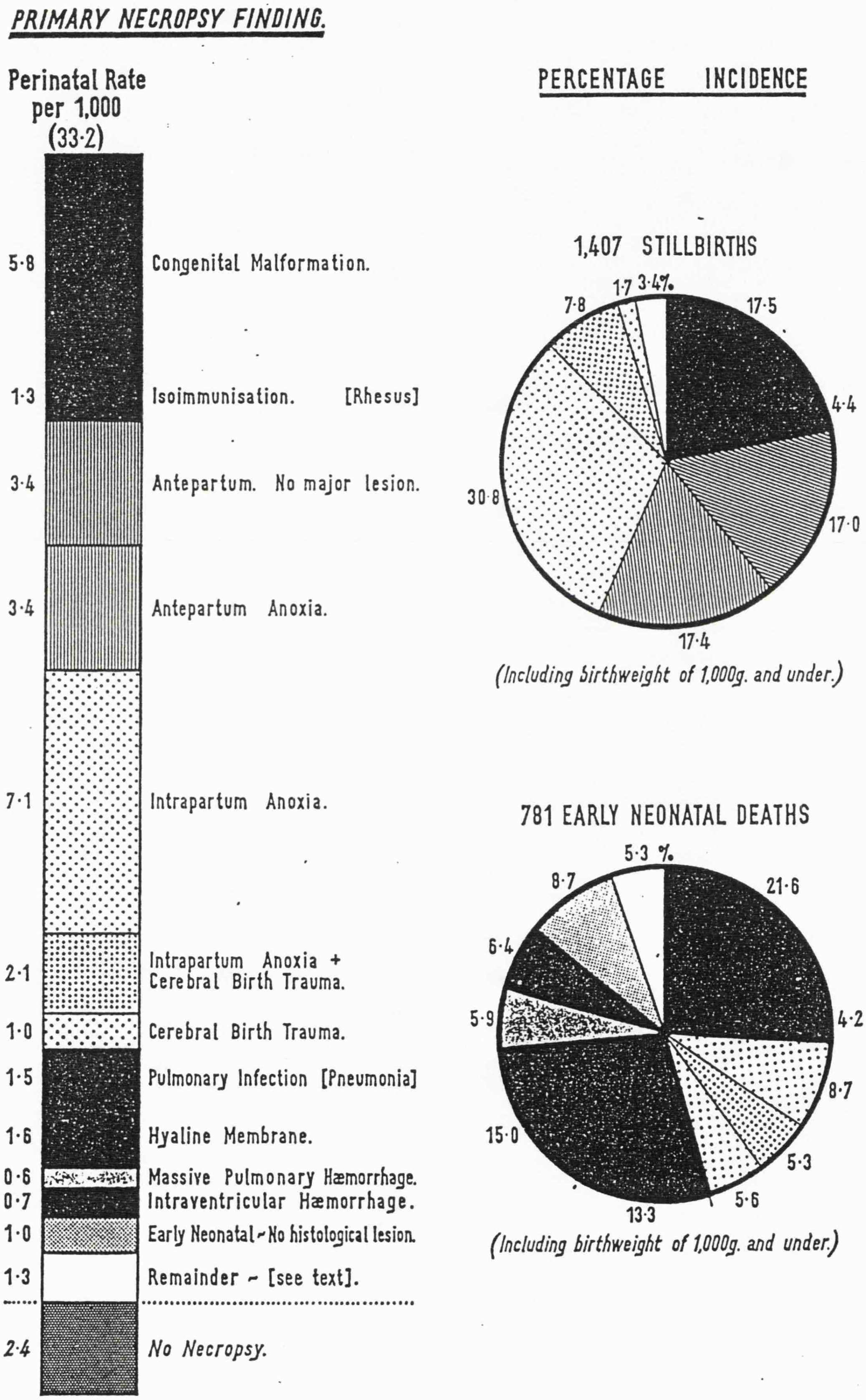
Table 2.2.1 Comparison of Social Class Distributions of OTA and OBD Subgroups with that of Total Population (at age 7)

CLASS	% OTA	% TOTAL POP.	% OBD
NO MALE HEAD	3.0	2.9	5.2
I	5.8	5.2	7.3
II	15.2	14.3	18.3
III NON-MAN	9.6	9.7	7.3
III MAN	43.7	44.1	37.3
IV NON-MAN	1.1	1.8	1.8
IV MAN	15.2	15.6	14.1
V	6.4	6.4	8.6

Table 2.2.2 Laterality Preferences of OBD and OTA Subgroups and of Total Population

AGE TESTED AND ORGAN :	SIDE	% OTA GROUP	% TOTAL POP.	% OBD GROUP
HAND AT 7	R	78.7	78.8	77.0
	L	7.7	7.5	6.8
	M	13.1	13.4	15.3
FOOT AT 7	R	61.1	57.4	57.7
	L	5.3	6.8	7.8
	M	33.1	35.3	33.3
EYE AT 7	R	56.3	58.8	58.0
	L	34.4	32.9	32.5
	M	8.5	7.8	8.2
HAND AT 11	R	85.6	84.0	
(MOTHER)	L	9.6	10.3	
	M	4.7	5.6	
HAND FOR WRITING	R	89.7	88.5	
AT 11 (MOTHER)	L	10.1	11.3	
	M	0.2	0.1	
HAND TO THROW BALL	R	90.6	90.2	
AT 11 (MEDICAL)	L	9.2	9.6	
FOOT TO KICK BALL	R	90.6	88.5	
AT 11 (MEDICAL)	L	9.4	11.4	
EYE FOR SIGHTING	R	63.2	67.6	
AT 11 (MEDICAL)	L	36.6	32.1	
HAND PREFERRED	R	89.2	88.4	88.3
FOR WRITING AT 16	L	10.5	11.3	11.4

FIGURE 2.3.1


PRIMARY NECROPSY FINDING.
Perinatal Rate per 1,000 (33·2)
5·8 Congenital Malformation.
1·3 Isoimmunisation. [Rhesus]
3·4 Antepartum. No major lesion.
3·4 Antepartum Anoxia.
7·1 Intrapartum Anoxia.
2·1 Intrapartum Anoxia + Cerebral Birth Trauma.
1·0 Cerebral Birth Trauma.
1·5 Pulmonary Infection [Pneumonia]
1·6 Hyaline Membrane.
0·6 Massive Pulmonary Hæmorrhage.
0·7 Intraventricular Hæmorrhage.
1·0 Early Neonatal - No histological lesion.
1·3 Remainder - [see text].
2·4 No Necropsy.
PERCENTAGE INCIDENCE
1,407 STILLBIRTHS
17·5
4·4
17·0
17·4
30·8
7·8
1·7
3·4%
(Including birthweight of 1,000g. and under.)
781 EARLY NEONATAL DEATHS
21·6
4·2
8·7
5·3
5·6
13·3
15·0
5·9
6·4
8·7
5·3 %
(Including birthweight of 1,000g. and under.)

APPENDIX 2.3

Further Details of Findings Using the NCDS Data.

I The PMS Data as Presented in 'Perinatal Mortality' [1]

Before going on to discuss "at risk" groups, the authors discuss deaths which may have been avoided. They say :

> "The assessment of avoidability of perinatal deaths proved to be very difficult ; the foetus often proved resistant to one or more lapses in the standard of care and it soon became apparent that a central assessment of avoidability would be impossible. The lapses of care, particularly in the management of toxaemia and of intrapartum anoxia were sufficient to indicate, however, that many of the perinatal deaths could have been prevented."

The following table (Table 2.3.1) shows the correlates of increased mortality ratios (defined on page 87), and the direction of correlation.

We have already given details of necropsy findings in the main text (Page 87). Figure 2.3.1 illustrates these findings in greater detail.

II The First Follow-up as presented in [2] and [7]

'11,000 Seven-year-olds' [7] concentrates on descriptive data, and generally only differentiates between boys and girls at 7 years. Its data base is also smaller, since it was a preliminary report, composed before all the data had been received and processed. Much of the information given below is therefore taken from 'From Birth to Seven' [2].

Findings are presented under the headings of attainment, behaviour, environment variables, sensory and medical factors, and effects of pregnancy and birthfactors.

Attainment. At age 7, 8% of boys and 5% of girls were thought to be in need of special help ; 3.1% of boys and 1.4% of girls were non-readers ; and 3.8% of boys and 3.1% of girls showed virtually no understanding at all of number work.

Of the variables tested, the one with the largest effect on all attainment variables was social class, with a steep decline in attainment from classes I to V. Other factors which had an effect were family size, overcrowding in the home, country, sex, father stayed on at school, mother stayed on at school, maternal grandfather's social class, working mother, amenities in the home, tenure and accommodation. However, many of these effects were small and in opposite directions for Reading and Number work, and the sex difference in Reading had disappeared by age 11 (but using a different test).

Early starters had higher attainment scores, independent of social class ; while children in atypical family situations had lower attainment scores in all social classes except IV and V.

12% were "backward readers" (a score of 12 or less on the Southgate Reading test) at age 7 ; of these, 40% were "maladjusted" (a score of 20 or more on the Bristol Social Adjustment Guides). 54% of "non-readers" (Southgate Score $\leq$ 3) were "maladjusted" compared with 10% of non-backward readers.

Behaviour At age 7, 13% of all children tested were considered "maladjusted" from teacher rating scores on the BSAG, with significantly more boys than girls so rated.

The largest effect was again associated with social class ; and most of the variables associated with attainment were also associated with behaviour, family size and sex having quite large effects.

Late starters contained more "maladjusted" cases, independent of social class.

Environmental Variables 7.8% of children were not living with both natural parents ; 2.8% were in households with no male head. 9.0% were in households where they were the only child ; and 14.0% where there were four or more other children.

11% of children were living in overcrowded conditions. Two thirds had moved house at least once since birth, and 13% had moved three or more times. 17% had changed school once since they were 5, and about 3% more than once.

70% of children attended school 90% or more of the time, but 9% attended less than 80% of the time.

Sensory and Medical Factors Speech was judged better in girls than in boys at 7 years, and ratings declined with social class. More boys had a history of speech difficulties, had a stammer at examination, had not fully intelligible speech, or scored lower on the speech test.

14% of children had some visual handicap, but in only 0.3% was this judged to affect schooling. The proportion of children with one eye better than the other rose steeply with degree of handicap in the better eye, from 10% of those with perfect vision. Squints were found in nearly 60% of children who had been prescribed glasses, were associated with "clumsiness", and were more prevalent in lower social classes.

5.7% of children were judged to have some hearing impairment, and 10.3% had been suspected of having difficulty.

Significantly more boys were rated left-handed and mixed-handed by mothers (11.3% and 8.7% compared with 8.8% and 5.9% for girls) but doctors found in a practical test that although more boys were left-handed (8.7% ; girls 6.1%), more girls were mixed-handed (12% boys ; 13.5% girls). The numbers for foot- and eye- preferences showed more boys in all non-right categories (Foot : Boys 8.2% L. 36.3% Mixed ; Girls 6.0% L, 34.2% Mixed ; Eye : Boys 35.1% L, 7.8% Mixed, Girls 32.3% L, 7.7% Mixed).

1 in 5 children had had accidents severe enough for hospital admission by age 7, slightly more of these were boys.

Boys were slower to walk, and the prevalence of non-walkers at 1½ years was also associated with both extremes of social class ; boys were slower to talk, and there were no social class differences ; and boys were slower to achieve bladder control, with a frequency trend from social class I to social class V. More boys also had fits in the first year of life.

More boys than girls (about twice as many) were judged to have abnormal activity levels or physical coordination ; there was a social class trend in frequency from Class I to Class V for both activity level and for fine motor movements, but no class differences for gross motor movements.

Of the original cohort of 17,418 births, 389 died shortly before or during birth and 280 in the first four weeks after birth. Causes of death between 1 month and 7 years are shown in Table 2.7 on page 90 in the main text. Serious defects in the cohort (excluding vision, hearing and speech) are shown in Table 2.8 in the main text (p.91). Of 34 severely subnormal children, 29 had associated defects ; while of 186 formally ascertained for special educational treatment, nearly two thirds had defects. Of those children in normal schools whose teachers thought they needed special schooling, about one fifth had defects.

Pregnancy and Birth Factor Effects

(i) Prediction of Handicaps The factors most predictive of sensory and physical defects and severe subnormality were birth order, method of delivery, and condition of baby in first week ; social class and birthweight-for-gestation did not improve prediction further. The factors most predictive of less severe mental retardation were birth order, social class, birthweight-for-gestation, and method of delivery ; condition of baby in first week did not improve the prediction. Table 2.9 in the main text (p.92) shows how successful these sets of predictors were for the NCDS cohort.

(ii) Relationships with recognised handicap, clumsiness and copying designs Some pregnancy and birth factors were investigated for their relationship with "recognised handicap" (teachers think special schooling needed) clumsiness (teachers rate child 'certainly' clumsy) and copying designs test score (score of 0 to 4).

Short gestation and long gestation, allowing for social class and birth order, both carried increased risk of 'educational backwardness' and 'clumsiness' at age 7.

Short gestation and light-for-gestation variables were related to poor copying designs scores, allowing for social class and birth order.

Light-for-gestation and heavy-for-gestation babies were also at risk for educational backwardness.

The only important association between the three outcome variables and severe pre-eclampsia, bleeding in pregnancy, foetal distress, prolonged labour, and abnormal method of delivery was between foetal distress and clumsiness.

The proportion of handicapped children and those thought to be in need of special schooling was increased amongst mothers who had not been attended by a trained person in labour.

(iii) Smoking in Pregnancy had an adverse effect on reading ability and social adjustment after allowance was made for a range of other variables.

TABLE 2.3.1 CORRELATES OF INCREASED MORTALITY RATIOS IN THE PMS

	Variable	Direction of Correlation (Size of Mortality Ratio)
(i)	Region	North and West generally higher than South East
(ii)	Unbooked Delivery	Generally much higher than for booked delivery
(iii)	Mother's height	Shorter mothers tended to have higher M.R.'s, independent of social class, parity and region
(iv)	Mother's age	M.R. rose steadily after age 30 ; it was also higher for under 20
(v)	Parity	From the fourth baby onwards M.R. increased steadily ; it was also higher than average for first babies
(vi)	Social class	M.R. increased steadily from Social class I to Social class V
(vii)	Past Obstetric History	Previous cases of abortion, premature baby, still birth, neo-natal death, toxaemia, ante-partum haemorrhage, and caesarean section, all increased M.R. in later pregnancy
(viii)	Pre-natal care	M.R. fell with number of pre-natal visits to 15-24 visits but rose again for more frequent visits
(ix)	Toxaemia	M.R. rose with increasing degrees of toxaemia, particularly for toxaemia proteinuria, and for gestation longer than term
(x)	Bleeding in Pregnancy	Bleeding before 28 weeks, accidental antepartum haemorrhage, unspecified antepartum haemorrhage and placenta praevia were all associated with increased M.R.
(xi)	Gestation	M.R. rose for gestation periods longer or shorter than 40 weeks, being almost double by 38 or 43 weeks. Long- and short-gestations tended to be more frequent in young mothers, high parities and Social class V
(xii)	Birthweight	Very low birthweight and low birthweight-for-gestation carried increased M.R. These categories tended to be more frequent for young - (<20) and older mothers - (>40), for unmarried mothers, and for Social class V
(xiii)	Labour	Short labour increased M.R. in all parities, long labour in first babies increased risk after 24 hours
(xiv)	Method of Delivery	M.R. high for breech delivery and caesarian section (which was related to the reason for the section). Forceps delivery carried higher M.R. for multiparae mothers and for very large babies (>4,000 gms.)

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CHAPTER III

INVESTIGATING MATHEMATICAL UNDERACHIEVEMENT USING DATA FROM THE NCDS

Previous use of the NCDS data to identify mathematical underachievers at the age of 11 is described, along with the analysis of variables connected with this underachievement. Next, our own analysis of the data and our identification of a group of Specific Mathematical Underachievers is presented. Finally, the search for variables and syndromes connected with Special Mathematical underachievement is described.

A NOTE ON METHODOLOGY

In Chapter II, we looked at the NCDS data in broad terms, at its strengths and weaknesses for the purposes of our proposed study in terms of the proposed methodology outlined in Chapter I.

When we look at it in terms of mathematical underachievement, we find that some potential causes of such underachievement cannot be tested. We have no measures of personality, motivation or attitude to Mathematics; nor have we any measures of good teachers, help from outside the school, teaching methods, or curriculae taught. These are quite serious drawbacks when attempting to look at the causes of underachievement.

On the other hand, it is not clear that such information should be treated as directly relevant to our study, even if it could be obtained. For, if dyscalculia exists, it is going to occur in conjunction with many other factors related to children's learning (though these may themselves be possible causes); for example, it is quite likely that some dyscalculics may also lack motivation or meet a bad teacher. Put another way, dyscalculia should not be seen as the result of "diagnosis by exclusion" in which, all other possible causes being ruled our, it is the only alternative left. Unless the 'related factors' are very plausible explanations in themselves for the cause of underachievement, they may well be the effects of neurological malfunctioning in mathematics. Nevertheless it certainly might aid our search for measurable, operational correlates of dyscalculia (assuming it does exist) if a relatively 'pure' group could be found in which complications of adverse social, educational, motivational or emotional factors were absent or minimal; and it would shed doubt on alternative explanations. It is difficult to decide whether the latter factors are causes or effects when they occur in cases of underachievement, but whichever is the case they impinge on our study and need looking at as closely as possible. We have therefore examined some of the social, educational, motivational and emotional factors via some of the relevant variables included in the NCDS data, although our main study has been to look for neurological links with underachievement.

UNDERACHIEVEMENT

So far, we have used the term 'underachievement' quite freely, without a precise definition or any proper discussion of the concept. Here we examine the concept of underachievement in more detail as it is a vital part of our concept of dyscalculia.

Underachievement can only exist in relation to a standard of expected or predicted performance. This standard has traditionally been the norm for the chronological age or the norm for the mental age. Schonnell [1] used "backward" and "retarded" for those children achieving below these two standards, respectively. Lavin [2] described performance relative to the chronological age standard as "high" or "low" achievement, and relative to the mental age standard as "over" or "under" achievement; a distinction which we have followed.

Several authors (e.g. Guilford and Fruchter [3], Thorndike [4], Lavin [2]) have pointed out that, because of the regression to the mean effect, if mental age (or IQ) is used as a predictor, very high scorers will tend to do less well on achievement measures and so be classified as underachievers, whereas the reverse will hold for very low scorers on the predictor. Thorndike [4] therefore strongly advocated using the regression of achievement on IQ to predict achievement from IQ. This method was successfully used for a study of Reading attainment by Rutter and Yule [5]; and has been strongly advised by Yule [6] for the identification of learning-disabled children. This latter definition of underachievement :

> achievement below that predicted from the IQ and the regression of achievement scores on IQ scores is called underachievement

will be used throughout our own investigation.

There are two drawbacks to such an unqualified definition; the first is that achievement above prediction is called 'overachievement', which is viewed by some as an anti-educational concept; the second is that almost all children will be under- or over-achieving, which reduces the significance of the concept. It is therefore necessary to qualify the definition by introducing a 'normal' range of under- and over-achievement.

It is clear that a choice of cut-off between those children whose score difference between actual and predicted scores is considered normal and those whose score difference is considered abnormal is completely arbitrary and roughly determines the percentage so labelled. Thorndike [4] advocates the use of the standard error of the regression to determine the cut-off point, which should be at least two standard errors below or above prediction (roughly 5.0% of the population).

Following this suggestion, as also advocated in Rutter and Yule [5] and May [7], we have chosen to take two standard errors below prediction as the cut-off for underachievement. This is done on the grounds that : such a group should be extreme (statistically less than 2.5% of the population); it should still be large enough for useful statistical comparisons (our population is roughly 14,000), and it should be comparable with similar studies (e.g. [5] and [7]); and, since underachievement is a function of the particular IQ and achievement tests used, it should be large enough, in terms of the tests' characteristics for the scale of marks to be discriminatory. In our case a child would have to score 12 marks (out of a possible 40) below expectation on a test designed to tap a common core of all

Mathematics curriculae to age 11, to be included in the extreme 'underachievers' group.

We also note that such a choice will in practice mean that no child expected to score less than 12 out of 40 on the Mathematics test can be included in the 'underachievers' group because of the particular form of the regression equation. That is, all children with an Ability score of 34 or less will be excluded from the group of Mathematical underachievers. In practice, this will mean that 31.5% of the NCDS children who did have a recorded Total Ability score at age 11, will be excluded. Such a percentage cut-off on a standard IQ test would correspond to an IQ of approximately 92. Thus all low-ability children will be excluded.

We now go on to describe the actual identification of our special sample of Mathematical underachievers in the NCDS. This will be done in two separate stages.

IDENTIFICATION OF OUR SMU GROUP

STAGE 1

As a first stage in identifying our sample we used the procedure carried out and described by May [7], who, to begin his own study of mathematical underachievement, had already identified mathematical underachievers from the NCDS data, stored at Bath, in the way described above.

The details of May's procedure were thoroughly checked and his basic sample accepted as also being a good starting point for the refined sample subsequently used in this study. In view of the relevance of May's work to the present investigation, it is reviewed here in some detail. Not only is it a study of Mathematical underachievement, but also it considers a wide variety of variables as predictors or correlates of mathematical underachievement, and it uses the NCDS data and overlaps with our own study.

(a) The Preliminary Sample (May [7])

In May's study, the regression of the Mathematics test score on the Total Ability score, at age 11, was :

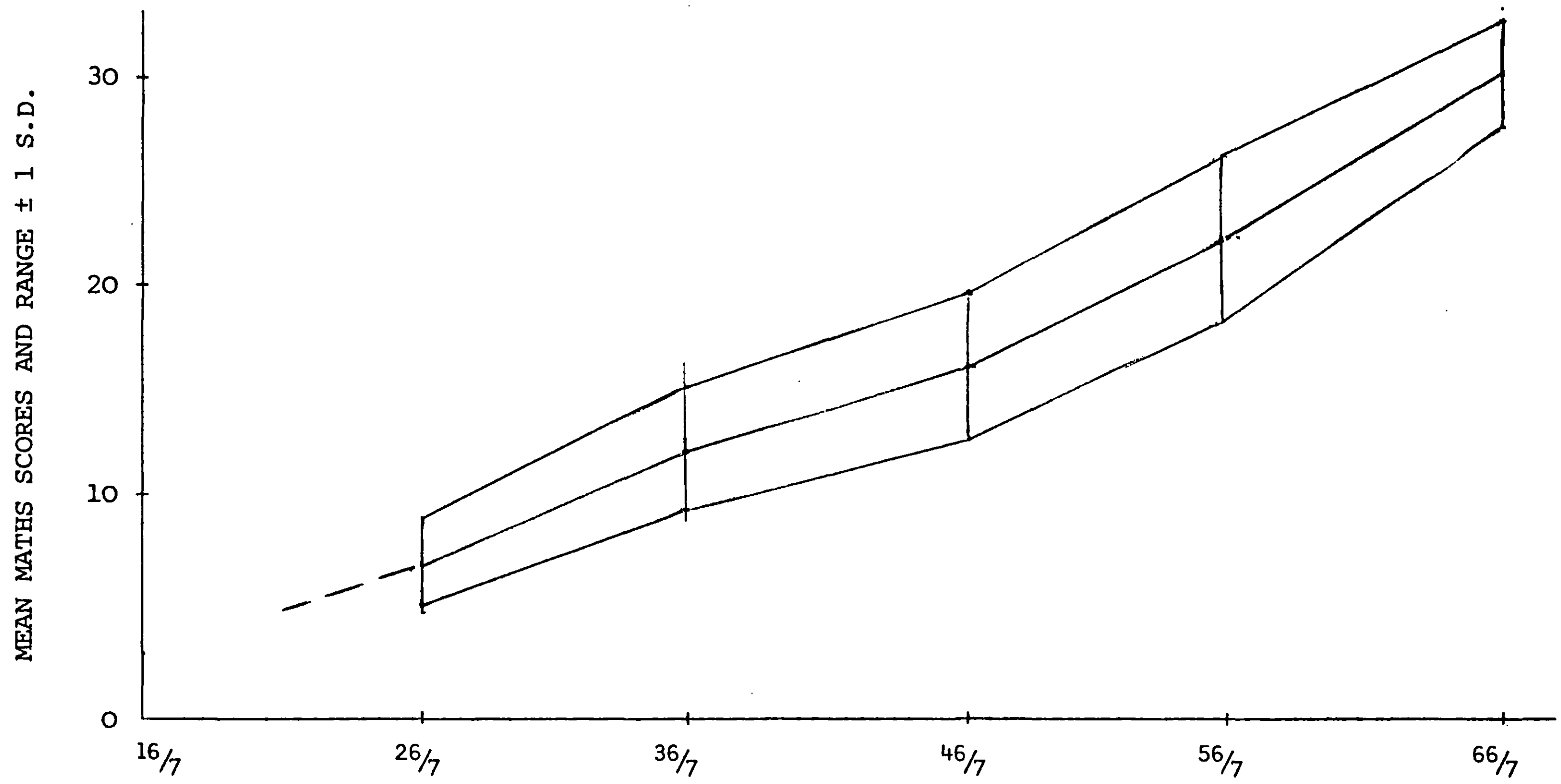
$$y = 0.52x - 5.71$$

where y = M test score; x = TA score, and the standard error of estimate was 6.09.

The assumptions for using a regression equation were tested. It was noted that the Mathematics test failed to discriminate well at the lower end of the scale, resulting in a truncated distribution. (See Appendix 3.1 for distributions on tests at age 11). Means and variances calculated for various sample levels on the predictor variable showed that there was some deviation from linearity in the regression line, but not seriously so. (See Figure 3.1, taken from May). Differences in variance were most marked at the extreme ends of the sample levels where floor and ceiling effects of the Maths score range caused some compression of the distribution. The truncation at the lower end of the distribution was considered the most serious deficiency, but, even so, the use of the regression equation

FIGURE 3.1

LINEARITY OF REGRESSION OF MATHS ON ABILITY



was considered justified.

This procedure identified 270 (97 boys, 173 girls) who were underachieving in Mathematics at age 11, and whose Total Ability score was 35 or more.

(b) May's Methodology and Results

Having identified his group (MU) of Mathematical underachievers, as described above, May [7] first attempted to find predictor variables - factors appearing in the PMS data or the 7-year data that would predict the observed underachievement at age 11.

May therefore divided the NCDS population (who had test scores at age 11) into six groups, one of which was MU, based on under- or over-achievement categories ($\geq$ 2 s.e.; ± 1 to 2 s.e.; ± 0 to 1 s.e. from prediction), noting that the under-achieving groups would contain too few children (see page 122) since some with low TA scores would be misclassified. He chose to compare these six groups, rather than compare extreme groups (which would fail to identify any variable whose effects were non-linear in any approximately U-shaped fashion), or use a continuous scale (which would be more difficult to visualise) on all available sound variables which were well-distributed.

Although this procedure is often criticised on the grounds that the testing of large numbers of variables will almost certainly result in spurious significances, it does have the merits in this case that : because of the sparcity of work in this area, many of the available variables had never been considered in connection with Mathematics underachievement; there was an inexact match between the variables available in the NCDS and those hypothesised as having a bearing on Maths underachievement, so that the testing of specific hypotheses would have been difficult.

May chose 62 PMS and 7-year variables, divided into sets of "perinatal", "family and social", "school", "teachers' ratings" and "other" factors; each set of factors being tested separately using (parametric) multiple regression analysis to find the largest-contributing factors to prediction of the underachievement categories. The resulting 25 factors were then combined and tested for the best predictors; these, together with their contributions, are shown in Table 3.2 (taken from May).

Two features of this table deserve comment. After the eight most significant predictors had been incorporated, only 10% of the variation was explained. By comparison, Hutchinson *et al* [8] were able to obtain 54% of the variation explained by just two variables in seeking to predict Mathematics attainment at age 16 from variables measured at age 11, as May also noted. Secondly, these predictor variables can be grouped roughly into three non-independent areas :

Attainment ratings at age 7 (variables 1, 3, 5);
Social class variables (4, 7, 8);
Neurological variables (2, 6).

It is not clear from the analysis, or May's work, where the greatest effects of the predictors arose; we should expect that attainment

TABLE 3.2

BEST PREDICTORS OF MATHS. UNDERACHIEVEMENT AT 11 FROM PERINATAL AND 7 YEAR DATA

VARIABLE	MULTIPLE R	R^2	b
Number Work (TR)	0.259	0.067	-0.192
Sex	0.284	0.080	-0.249
Arithmetic Test Score	0.301	0.090	0.046
Father stayed on at School	0.307	0.094	-0.099
Reading (TR)	0.312	0.097	-0.052
Physical co-ordination (TR)	0.316	0.100	-0.121
Mother's father's social class	0.318	0.101	-0.030
Child's height	0.320	0.103	-0.002
		constant	5.300

TABLE 3.3

BEST PREDICTORS OF MATHS UNDERACHIEVEMENT AT AGE 11 FROM PERINATAL, 7 YEAR AND 11 YEAR DATA

VARIABLE	MULTIPLE R	R^2	b
Number work at 11 (TR)	0.334	0.111	-0.304
Sex	0.360	0.129	-0.240
Arithmetic Test Score at 7	0.370	0.137	-0.032
Poor Control of Hands at 11	0.373	0.139	-0.126
Number work at 7 (TR)	0.376	0.141	-0.071
Social Class	0.378	0.143	-0.028
Streamed Class at 11	0.380	0.144	-0.010
Ball kicking at 11	0.381	0.145	-0.098
		constant	5.289

ratings at age 7 might have some predictive value for both over- and under-achievement, but that social class variables might have more effect on 'over' than on 'under' achievement. But the significant finding, from our point of view, is that two 'neurological' variables, sex and physical co-ordination, were among the best predictors.

When 11-year data (excluding educational test scores) were added to the total set of predictor variables, the eight best predictors were somewhat different, and the variance explained increased to 14%, as is shown in Table 3.3 (taken from May). The same three categories of predictor variables appeared (1, 3, 5, 7; 6; 2, 4, 8), this time including three 'neurological' variables, sex, poor control of hands, and ball kicking, among the best predictors.

The significance of finding 'neurological' variables among the best predictors was not mentioned by May, but he did comment on one of them, namely sex.

Quoting Lavin [2] that girls perform more nearly in accordance with their measured ability than do boys, and support for this in Rutter and Yule's [5] study of Reading underachievement, May pointed out that it was contradicted for Mathematics underachievement in the NCDS data, since there were more girls in all three underachievement categories and more boys in all three overachievement categories. In spite of the links with neurological factors noted in Tables 3.2 and 3.3, and with social factors (father stayed on at school, mother's father's social class, child's height, social class), May concluded that sex stereo-typing was the most likely explanation, even though sex differences in Mathematical ability atypically showed up as early as 7 years in the NCDS data.

For the second part of his study, May looked specifically at the MU group.

He first showed that, contrary to the findings of Rutter and Yule [5], the groups of severe Mathematical underachievers (MU) and severe Reading underachievers (defined analogously using the regression of Reading Comprehension scores on Ability scores) in the NCDS were distinct. There were 258* in the MU group, 175 in the RU group and only 24 in both. Moreover, the fact that only about 20% (similar for both boys and girls) of the Mathematical underachievers scored less than 30% correct on the Reading test, suggests that low Reading attainment is not a major explanation of Mathematical underachievement.

The MU group was then compared with the rest of the population on 157 chosen variables, using chi-squared tests and for the sexes separately. Only one variable, of those studied, was significant for both sexes ($p < .05$) : "parent initiated discussion at age 11", but applied to fewer boys and to more girls in the MU group. Significant variables for the boys only were "family moves from birth to 7" (more MUs had moved two or more times), "number of schools attended to age 7" (more MUs had attended three or more schools, but this was reversed for the girls), and "father stayed on at school" (fewer in the MU

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* The difference in numbers is due to children who lacked one test score at age 11.

group). Significant variables for the girls only were "mother's interest" (fewer MUs rated very interested, but similar proportions showed little or no interest), "class size at age 7" (more MUs were in classes of < 25, fewer were in classes of > 43), "attended LEA nursery" (fewer MUs had attended, and this also applied to the boys), and "smoking in pregnancy" (more MU mothers changed their smoking habits during pregnancy).

In order to assess the possibility that these variables were genuinely significant, and not spuriously so because of the large number of variables considered, May then grouped the variables into 4 areas, each of which was examined for supporting evidence amongst related variables which previously had failed to reach significance. The areas chosen, on the basis of the significant variables, were mobility, birth factors, parental, and school. Correlations between variables within each of these areas and elementary linkage analysis reaffirmed that mobility may be a factor in underachievement for boys only. There was a slight suggestion that birth factors were related to attendance for girl underachievers.

This latter point, if verified in other studies, would lead to two possibilities : that adverse "birth factors" may lead to later ill-health and so cause absence from school, and this in turn could easily explain Mathematics underachievement as due to missed explanations of concepts (as well as lack of practice) combined with the hierarchical nature of mathematics (see Chapter IX); or that adverse "birth factors" may affect the mental status of the child, the latter leading to underachievement in some areas (i.e. dyscalculia, dyslexia, etc.), and that either the physical health of the child was also affected, or that absence from school was caused by reaction to the underachievement.

To sum up this study, there was support for neurological involvement in Mathematical underachievement both from predictor variables and from comparison of severe underachievers with the total population. Severe underachievement in Mathematics and in Reading appear to be largely distinct, and low Reading attainment did not appear to be a major explanation of Mathematical underachievement.

STAGE 2

Rationale for our Experimental Group

The above review contains illustrations of some important points which we have previously discussed, directly or indirectly, and which are well worth repetition here.

Firstly, underachievement is a very different concept from attainment, as May's attempts to find predictors well illustrates. Moreover, his best predictors contain different types of variable from those which best predict attainment, suggesting that underachievement is influenced by different factors.

Secondly, all cases of underachievement are unlikely to have a common cause; that is, there is unlikely to be any factor common to all such cases. This is illustrated by the comparison of Mathematics underachievers with the population and by the very small amount of variance explained by the predictor variables. Indeed, May's work supports our contention that underachievement can have any of the causes hypothesised in Chapter I, all of which are entirely credible and supported by at least some evidence in the literature. However, it does seem likely that cases can be grouped in such a way that each group is related strongly to one common factor, or group of common factors.

This latter point, together with the discussion at the opening of this chapter concerning the advantages of using a "pure" subgroup of underachievers leads us to go on beyond May's work, to ask :

> Is there any evidence that there is a group of children who underachieve in Mathematics and who are not typical of groups dominated by emotional factors, socio-economic factors, poor teaching, or other non-neurological factors, and for whom there is some evidence of a neurological defect?

If we could find such a group, it would go some way towards a validation of the concept of dyscalculia. [Of course, this would merely be the foundation for further investigation, since 'neurological defect' is likely to cover a range of possible defects, each of which has its own peculiar effect of Mathematical performance; that is, dyscalculia is not expected to be a unitary condition (see Chapter I)].

A first step towards the identification of such a group was suggested by another of May's findings which he failed to pursue, namely, that severe underachievement in Reading appeared to be separable from that in Mathematics. This led us naturally to consider a more specifically mathematical underachievement which fits with our definition of dyscalculia. Therefore, in order to look for such a group in the NCDS data, two approaches were taken. For both, the size of the preliminary experimental group of underachievers was reduced to try to eliminate some of the unwanted factors (see below). The resulting group of "specific Mathematical underachievers" (SMU group) was first compared with the total population on a wide range of variables, in order to look for significant groups of variables distinguishing it from the population. Secondly, the individual members of this SMU group were looked at as separate case studies, with a view to revealing some characteristic subgroups related to the hypothesised causal factors. Each subject was profiled for "abnormal" values of the variables, and linked groups of such variables were sought.

The idea of this latter approach is that any single factor strong enough to cause this degree of underachievement should be relatively prominent in such cases, and any related group of variables from the NCDS may be seen to cluster together.

The rationale for the SMU group is that any factor causing Mathematical underachievement is more likely to become more prominent when cases of 'pure' Mathematical underachievement are isolated from cases where underachievement extends to Reading Comprehension as well. The latter 'general' underachievement may be due to social factors, which are generally found to affect Reading as much as, or more than, Mathematics.* "General" underachievement is also more likely to result from emotional disorders (except acute anxiety specific to Mathematics as suggested by Buxton [9]), especially when such disorders clearly precede the underachievement, absence from school (although the hierarchical nature of Mathematics may in some cases mean that the effect on Mathematics is greater than on other subject areas; see Chapter IX), and, to some extent, poor teaching (since in many junior schools and most infant schools the same teachers will have been responsible for both Reading and Mathematics; it will not be true for pupils having separate subject teachers, or for teachers specifically poor at teaching Mathematics).

Thus, by excluding those children whose underachievement is more pervasive, we also exclude some members of the groups of Mathematical underachievers with non-neurological causal factors. We may also, theoretically, be excluding those dyscalculics, assuming dyscalculia exists, whose neurological impairment affects other areas of achievement. This could be convenient in some ways, however, as it reduces the effect of interactions between Mathematics and other academic areas (e.g. poor reading may affect performance in all other academic subjects). However, it may also make our search for a link between Mathematics underachievement and neurological variables more difficult by excluding the most severe neurological impairments. These considerations will need to be borne in mind when considering the resulting sample.

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* Indeed, in this NCDS study, social class differences in Reading attainment were always more pronounced than those in Mathematics attainment.

THE SMU GROUP

The SMU group was formed from the group of severe mathematical underachievers (pages 123 & 124) by excluding all those children whose Reading Comprehension score was more than one standard error below prediction based on Total Ability score. It contained 142 children of whom 55 (31%) were boys and 87 (61%) were girls - a very slightly lower proportion of girls than in the whole severely underachieving group (64%).

Table 3.4 (summary) and Appendix 3.2 (full record) show the abilities and attainments at ages 7, 11 and 16, of this SMU group.

TABLE 3.4

ABILITIES AND ATTAINMENTS OF SMU GROUP

TEST	MEAN SCORE	MEAN DISCREPANCY
Total Ability Age 11	56.1 (Pop. 42.9)	
Maths. Tests Age 7	4.6 (Pop. 5.1)	
Age 11	8.7 (Pop. 16.6)	14.8
Age 16	10.9 (Pop. 12.8)	5.7 (Assuming Ability unchanged)
Reading Tests Age 7	25.8 (Pop. 23.3)	
Age 11	19.2 (Pop. 16.0)	0.6
Age 16	27.9 (Pop. 25.3)	1.5 (Assuming Ability unchanged)

When the SMU group was compared with the total population on all 317 variables used in our study, the variables found to be significantly different ($\rho \leqslant .05$) are shown in Table 3.5.

TABLE 3.5

SIGNIFICANT DIFFERENCES BETWEEN THE SMU GROUP AND THE POPULATION

Variable	Direction of Difference & Comments
Mathematical Ability at Age 7 : Teacher rating	SMUs worse
Reading Ability at Age 7 : Teacher rating	" better
Problem Arithmetic score Age 7	" worse
Southgate Reading score Age 7	" better
Mispronunciations on speech test Age 7	" " (sig. 10 at age 11)
*Sex	" more girls
Help for mental backwardness at Age 11	" fewer
General knowledge at Age 11 : Teacher rating	" better
Mathematics at Age 11 : Teacher rating	" worse
Use of books at Age 11 : Teacher rating	" better
Oral ability at Age 11 : Teacher rating	" less bad
Verbal ability test score at Age 11	" better
Nonverbal ability test score at Age 11	" "
Total Ability test score at Age 11	" "
Reading Comprehension test score at Age 11	" "
Mathematics test score at Age 11	" worse
Copying Designs test score at Age 11	" " (on categorised scores, average scores not quite sig.)
Nervous symptoms at Age 11 : Teacher rating	" fewer
'Outsiders' at Age 11 : Teacher rating	" more
Contact with emotional/behavioural clinic by Age 11	" more
Mathematics ability Age 16 : Teacher rating	" worse
" " " : Child rating	" "
English ability Age 16 : Teacher rating	" better
" " " : Child rating	" "
Science ability Age 16 : Teacher rating	" worse
Practical subjects Age 16 : Teacher rating	" less bad
Social studies Age 16 : Teacher rating	" more average
Reading Comprehension test Age 16	" better
Mathematics test Age 16	" worse
Parents dissatisfied with child's school Age 16	" more
Accidents involving hospital/casualty departments	" more

* See discussion on page 126.

DISCUSSION OF SIGNIFICANT VARIABLES

Ability and Attainment

The clearest pattern to emerge from this investigation of the SMU group is the consistency of its members' performance relative to the population. At 7, 11 and 16 years, for both Teachers' ratings and attainment test scores, the SMU group were above average at Reading (or English) and below average at Mathematics (or number work).

This strongly suggests :

(i) that measurement errors are not a major factor in the identification of the SMU group;

(ii) that Reading and Ability scores are consistent with each other, and that the group as a whole is consistently underachieving in Mathematics throughout most of the learning period (school ages).

Emotional Variables

Three emotional behaviour variables ('outsider', nervous symptoms, and contact with emotional/behaviour clinic) were significant at age 11, but none reached significance at ages 7 or 16. The latter (age 16) may be due to the large number of missing data cases, or to the fact that the Bristol Social Adjustment Guides were not used at age 16, and the ratings that were used may not be comparable.

How these variables relate to the underachievement it is impossible to say : they may be cause or effect or neither. (See earlier discussion).

Looking at emotional/behavioural variables using the Bristol Social Adjustment Guides (BSAG) at ages 7 and 11, we found that at both ages 11.3% of the SMUs were 'maladjusted' (BSAG total score > 20) compared with 11.9% and 11.5% of the total population at 7 and 11 respectively. Of these 'maladjusted' SMUs, 5 (approximately 4%) were so at both 7 and 11 years.

The data also revealed children with very high BSAG scores who were achieving or over-achieving in Mathematics, so that 'maladjustment' clearly does not necessarily lead to underachievement.

Our SMU group was chosen so that only Mathematics achievement was severely below expectation, based on measured ability, so that if we postulate 'maladjustment' as a cause, we have to explain why its effects were mainly confined to Mathematics.

On balance, we think that there is probably a small subgroup of the SMUs whose underachievement in Mathematics may be caused (or, at least, very much aggravated) by emotional factors.

The poor performance of the SMU group on the Copying Designs test at age 11 (and at age 7, although the latter did not reach significance) has some collaborative evidence in the literature and can be related to causes of Mathematical underachievement. Kosc [10] found that some of his 'dyscalculic' children had difficulty in copying complex figures (see Chapter I, page 23). The poor performance may have arisen as a result of failure in one of two areas : the actual execution of the drawing, or the conception of what was to be drawn.

Factors related to the former are poor physical co-ordination and poor eye-hand co-ordination. But teachers rated fewer SMUs as having 'poor physical co-ordination' or as 'clumsy' at 7 years, although at 11 years the proportion of SMUs rated as having certainly poor physical co-ordination was higher than the population proportion. A higher proportion of SMUs were rated as having 'poor hand control' at age 7, although more of these were 'somewhat', fewer 'certainly' than in the total population, but the proportion had fallen to slightly below that of the total population by age 11. In a practical test, SMUs were worse at catching a ball with either hand, on average, and proportionally more SMUs scored 0/10 on this test.

Factors related to the conception of what was to be drawn are directional discrimination and the grasp of spatial relationships. The NCDS data did not address these questions but we found in our case studies in local schools (see Chapter IV) that many of the children underachieving in Mathematics could not distinguish right and left or had difficulties with mirror images. Left-Right discrimination at age 7 was found to be the best predictor of learning difficulties in Nichols and Chen's [11] prospective study of Minimal Brain Dysfunction. The ability to grasp relationships between different parts of a design, an aspect of spatial ablity, also contributes to drawing complex mirror-images. It may relate to ability to see relationships between Mathematical concepts, or to analyse diagrams and problems into their component parts.

Non-Significant Differences Between SMUs and the Population

We next present a summary of our findings in connection with differences between the SMU group and the total population for variables which did not reach the 5% level of significance but which, nevertheless provide evidence related to some suggestions of factors affecting Mathematical underachievement. The variables have been roughly grouped into six categories :

(1) Sensory variables : The SMU group compared favourably with the total population on all sensory variables : sight, hearing and speech; only two children were considered to have even a moderate handicap (both sight) in the SMU group.

(2) Attendance variable : The SMU group were worse attenders on average at 7, 11 and 16 years. However, this arose because, although there was a similar proportion of 'bad attenders' (< 80% attendance), there were slightly fewer 'good attenders' (> 90% attendance). This suggests that attendance in itself was not a significant factor in Mathematical underachievement (especially since Reading did not suffer comparably); but attendance combined with some other factor (e.g. no compulsion to catching up on lost ground because of large class size, poor teacher, etc., so that missed work was never compensated for) may have been implicated in a small minority of cases. On the other hand, it is also possible that poor performance at school was a discouragement to attend. (See also the discussion, on page 128, of May's [7] finding that for girls birth factors were apparently linked to attendance).

(3) Social Class and Parental Variables : SMUs tended to have fathers in non-manual occupations relative to the total population and more were in private schools, especially up to age 11. Fewer SMU parents were thought to have 'little or no interest' in the child's progress in school. It thus seems unlikely that many of these children were underachieving because of deprivation or lack of parental interest and support. Their progress in Reading (generally much more affected by 'Social Class' and 'Parental Interest' variables in the NCDS data) also supports this view.

(4) Birth Data : Although, compared with the total population, there were fewer "at risk" babies in the SMU group (in the sense of mortality ratio > 1, as defined in Butler and Bonham [12]), there were, nevertheless, quite a number of SMUs "at risk". Table 3.6 gives the numbers and risk factors for those SMU babies who were "at risk" in the above sense.

(5) Co-ordination Variables, etc. : The pattern of findings was very complex, due to the use of different variables or measures at different ages, and to the changing patterns within variables due to categorisation. Table 3.7 summarises these findings.

This complex pattern, relative to the general population, can be interpreted in several ways :

TABLE 3.6

"AT RISK" BABIES IN THE SMU GROUP

No. of Cases among SMUs	Total SMUs with Data	Risk Factor	Mortality Ratio of Risk Factor
11	125	Gestation < 266 days	1.59 to 25.72
6	131	Mother very short or very tall (< 5', > 5'6")	1
3	120 (18	Birthweight > 2 s.d. below normal	1.0 to 28.08
7	estimated)	Birthweight > 2 s.d. above normal	1.0 to 2.39
*3	138	Bleeding in Pregnancy (all categories)	2.37 to 18.19
32	138	Abnormal Pregnancy (all categories)	1.0 to 18.19
16	138	Abnormal Delivery (all categories)	1.25 to 16.85
10	138	Foetal Distress (all categories)	1.14 to 11.64
*45	138	Raised Blood-pressure and/or Proteincuria (all categories)	1 to 8.6
37	138	Mother's age (≤ 20; ≥ 35)	1.07 to 2.54

* Up to 14 times the population rate

TABLE 3.7

COMPARISON OF SMU GROUP WITH POPULATION ON "CO-ORDINATION" VARIABLES

Variable	Age Group	SMU Compared with Population
'Poor control of hands' - TR	7	more 'somewhat', fewer 'certainly'
" " " "	11	fewer
'Poor physical co-ordination' - TR	7	fewer
" " " "	11	more 'certainly'
'Clumsy' - TR	7	fewer
'Difficult to understand because of poor speech' - TR	7	fewer
'Difficult to understand because of poor speech' - TR	11	more 'certainly'
'Always moving about' - TR	7	more 'certainly'
" " "	11	fewer
Standing heel to toe	16	more 'very unsteady'
Hopping on Left foot	16	more 'very unsteady'
Hopping on Right foot	16	more 'very unsteady'
Ballcatching with Left hand	16	fewer catches
" " Right hand	16	fewer catches
Number of squares marked in 1 min.	16	slightly higher
General motor handicap	16	more (but no severe cases)
Time to pick up 20 matches	16	slightly faster

(i) Two thirds of the SMU group are girls : girls tend to be rated as better co-ordinated, especially before puberty; if results were sex-weighted to allow for this, the ratings at age 7 would be more in line with those at 11 and 16. Also, the 'poor control of hands' and 'always moving about' variables may be taken together; a child who is always on the move is unlikely to get enough practice at fine hand control to keep up with more sedentary peers. At age 11, when activity ratings were lower, hand control was better.

(ii) Some of the SMU group experienced a developmental lag in co-ordination. At age 7, although this lag showed up in 'poor control of hands', girls' natural advantage in physical development may have been enough to hide other manifestations. But by 11 years, practice effects had made up the deficit in hand control, boys were more nearly equal to girls in general, and the lag was more obvious in physical co-ordination and speech.

(iii) Some of the SMU group experienced a neurological malfunction which affected mathematics, copying designs and certain aspects of co-ordination. Unlike explanation (ii), this implies that the malfunction is permanent and will not be 'grown out of'; although it might be ameliorated by compensatory strategies or time, as occurs in some cases of physical malfunction following brain damage (e.g. Luria [13]).

There is probably some truth in all of these interpretations; in particular, we shall see later that for some of the SMU group (iii) may well be the correct interpretation. A follow-up later in life which found persisting co-ordination difficulties would lend support to this view. More slight support comes from the further findings that the SMU group were more likely to have had fits in the first year after birth (but not later), more likely to have suffered concussion or head injury (to age 7), more likely to be epileptic, and more likely to have "neurological, muscular or orthopedic" disorders.

(6) Laterality Variables : At ages 7, 11 and 16 there were differences in laterality preferences between the SMU group and the total population; in particular, there were more left-handed writers in the SMU group. In view of the often-found connection between handedness and other laterality variables and dyslexia or other learning difficulties, these differences in laterality preferences may be relevant to the study of dyscalculia.

At age 11, the children were asked to throw a ball, kick a ball and sight through a tube, each performed twice. For each of these operations one child in the SMU group changed hand, foot and eye on the second occasion. But in the whole population such changes were rare (8, 14 and 5 our of 12,800 for hand, foot and eye, respectively).

The question of laterality preferences will be taken up in more detail in Chapter VI.

COMPARISON OF THE SMU GROUP WITH OTHER SUBGROUPS

We have already seen (page 122) that the definition of the MU and SMU groups meant that children of low ability (TA score less than 35 out of 80) were automatically excluded from these groups. In fact, most of the SMU group came from a middle-ability band (TA score in the range 30 to 60 out of 80), and since we will use this middle-ability band for comparison purposes in Chapter VIII, we also decided to use it to compare the SMU group with children of roughly the same ability range.

This comparison produced almost the same pattern of SMU disadvantages as the comparison with the total population, but differences tended to be more extreme. For achievement and ability, variables, SMU advantages were reduced. In particular, there were fewer backward children in the middle-ability group, so that the SMU group compared more unfavourably in this respect. Behaviour ratings tended to be better, and again the SMU group compared more unfavourably. In particular, behaviour ratings at age 7 showed that the SMU group were less 'anxious for acceptance by adults' and 'less hostile to adults', but other ratings were similar or higher (worse) for the SMU group. At age 11, the SMU group were 'less anxious for acceptance by children' and had fewer 'nervous symptoms', otherwise ratings were similar or higher for the SMU group, with 'childish behaviour' significantly worse. At age 16, ratings of 'irritability and touchiness', 'resentfulness and aggression', 'absence for trivial reasons' and 'worrying about many things' were all significant. At ages 7, 11 and 16, ratings of co-ordination were all worse for the

SMU group, with ratings of steadiness standing heel-to-toe at age 16 reaching significance. Comparison on pregnancy and birth factors showed that an even larger proportion of SMU babies were 'at risk' compared with the middle-ability group.

This pattern of findings confirms that factors which may relate to a 'neurological' explanation of Mathematical underachievement, including 'at risk' birth factors, poor co-ordination and laterality factors were more prevalent in the SMU group compared with the population, and even more so when compared with a similar ability group.

We also decided to compare the SMU group with the subgroup of children who scored 'top marks' in the Mathematics test at age 11, regardless of ability. The idea was that, if there is some set of circumstances present in the NCDS data, which differentiated children who could do Mathematics from those who could not (most of the Top Mathematics group were 'overachievers') this comparison might highlight the factors involved. Also, were the comparison to find as many or more 'neurological' factors among the Top Mathematics group, it would shed considerable doubt on our concept of dyscalculia.

The Top Mathematics (TM) group consisted of the 86 children who scored 39 or 40 marks (out of 40) in the Mathematics test at age 11. It differed significantly from the total population, the Middle Ability group and the SMU group on a wide range of variables such as social class (generally higher), average ability (higher), age at which phonics and sums were begun (generally earlier), parents' interest (generally greater) etc. Detailed comparisons are therefore omitted, but some are worthy of note.

(a) Sex : Whereas almost two thirds of SMUs were girls, only 44% of TMs were girls. The tendency for more high-scoring boys on the Mathematics tests (e.g. at age 11, 15 boys but only 4 girls scored full marks) was present at 7, 11 and 16 years in the NCDS data. This suggests that girls in general may have more difficulty with Mathematical problems (only 1 or 2 of the questions on the three tests combined called for only "mechanical arithmetic", in which girls are often found to equal boys) and that this difficulty may be present as early as 7 years.

(b) Achievement : Table 3.8 shows the comparison of achievement and ability test scores for the TM and SMU groups. It will be seen that, given their measured ability, the TM group had only slightly better achievement records than the SMU group for Reading, but for Mathematics, by the criteria used in their definitions, the TM group did better than expected and the SMU group worse. This latter pattern is also seen, although very weakly, in the Copying Designs test scores. A partial explanation of the significant difference in the average scores of the two groups on this test may be differences in co-ordination. The proportions of the two groups described as having 'poor co-ordination' and being 'clumsy' were not significantly different, althogh more SMUs were so rated, but 'poor control of hands' did reach significance at both 7 and 11 years. However, comparison with the total population has shown that co-ordination is unlikely to be

TABLE 3.8

COMPARISON OF TEST SCORES FOR SMU AND TM GROUPS

Test	Average Score		Range of Scores		Expected Average Scores		No. below Expectations	
	SMU	TM	SMU	TM	SMU	TM	SMU	TM
Total Ability at 11	56.1	68.2	36 to 77	49 to 79				7 scored < 60
Problem Arithmetic at 11	4.6	8.2	0 to 9	4 to 10	6.6	8.0		
Southgate Reading at 7	25.8	29.1	5 to 30	21 to 30	29.9	30.0		
Mathematics Test at 11	8.7	39.2	0 to 20	39 to 40	23.4	29.8		
Reading Comprehension at 11	19.2	26.1	11 to 28	19 to 33	19.8	23.3	83;0 1 s.e. below	22;4 1 s.e. below

a full explanation of poor copying design scores.

(c) Emotional Indicators : Ratings on the BSAG for the SMU group were generally higher (i.e. 'worse') than for the TM group. Table 3.9 shows the pattern of results.

From Table 3.9, we can see that the TM group were by no means free of symptoms (one had a total score of 36, whereas a score of 20 is generally taken as indicative of maladjustment); conversely, the SMUs did not all have symptoms. Thus emotional maladjustment does not appear to be a widespread fundamental cause of Mathematical underachievement but our results are consistent with the hypothesis that it could be a contributory factor in some cases (see also pages 135 & 136), and a possible effect in others where it may be seen as a general syndrome of maladjustment related to underachievement.

(d) Sensory Variables : These seemed unlikely to be implicated in Mathematical underachievement on our comparison of the SMU group with the total population. This is further supported by the finding that the TM group contained a slightly larger proportion of children with poor sight, a similar proportion with hearing difficulties, and slightly more children with speech difficulties at age 7.

(e) Attendance : Although on average the SMUs were significantly worse attenders than the TMs, this was due to a small minority, since 84.4% at age 7 and 91.3% at age 11 were rated good attenders. That absence from school does not necessarily impair Mathematics performance is shown by the facts that 3 TMs were "frequently absent" (9 SMUs), and

TABLE 3.9

COMPARISON OF BSAG SCORES FOR SMU AND TM GROUP

BSAG VARIABLE	SIG. AT 7	SIG. AT 11	COMMENTS
Unforthcoming	Sig.	Sig.	2 TMs had very high scores
Withdrawal	N.S.	Sig.	1 TM " " " "
Depression	Sig.	Sig.	
Anxiety for acceptance by children	N.S.	N.S.	1 TM " " " "
Anxiety for acceptance by adults	N.S.	N.S.	
Hostility to adults	Sig.	Sig.	1 TM " " " "
Writing off adults	Sig.	Sig.	2 TMs " " " "
Hostility to children	Sig.	Sig.	
Restlessness	Sig.	Sig.	
Inconsequential behaviour	Sig.	Sig.	
Total syndrome score	Sig.	Sig.	1 TM had total score of 36

2 TMs had "long absences" (11 SMUs). This supports our view that attendance *per se* was not a major factor in the SMU group's poor Mathematics performance, but was probably implicated in a very few cases.

(f) Social Class and Parental Interest : For all these variables, the SMU group tended to score or rate somewhere between the total population and the TM group. The latter group (TM), although biased towards the higher social classes, nevertheless contained a proportion of all social classes; and, although most parents were rated as being interested, at least one set of parents showed "no interest", and several had made no initiative to discuss the child with teachers. However, there is no doubt that all these variables are in the expected direction, and one important difference between a TM with a total ability score of only 49 and a SMU with a total ability score of 70 may be parental interest and guidance, but it is clearly not the whole story.

(g) Family and Mobility : Up to age 7, family moves and number of schools attended were similar, but by age 11 fewer SMUs had moved home more than once but more had moved more than four times (3 SMUs and 1 TM had moved 7 times), while fewer SMUs had attended more than 3 schools. Significantly more SMUs than TMs were only children, fewer were second children, and more were fourth. Only one SMU, but six TM children, spoke no English at home at 11 years.

While no TM families contained known cases of mental illness or neurosis, or mental subnormality, seven SMU families contained cases of mental illness or neurosis, and two contained cases of mental subnormality.

These data seem to suggest that although home and school moves and language spoken at home may result in some reduction in Mathematical achievement compared to measures of general ability, it is by no means a consistent factor. The mental status of family members may be more clearly implicated in some small minority of cases of underachievement.

(h) Birth Data : Adverse factors ('risk' factors in the Perinatal Mortality Survey) were found more often among the SMUs than the TM group. Bearing in mind the theory* that those factors which in severe cases lead to the death of the baby may in less severe cases lead to mental handicap, or in their milder forms to learning difficulties, it is interesting to note some of the comparisons between SMU and TM groups. More SMUs were premature (< 38 weeks) or late (≥ 43 weeks), more were small or very small (< 5½lbs), more mothers were very young (twice as many ≤ 20 years) or old (twice as many > 35 years). There were fewer cases of foetal distress among the TMs, in particular no cases of meconium and/or foetal heart. Fewer TM mothers had had bleeding in pregnancy or other abnormal pregnancies, in particular there were no cases of placenta praevia and accidental APH or bleeding pre-28 weeks, and fewer had had raised blood-pressure and/or proteinuria. Sixteen SMUs and eleven TMs experienced abnormal methods of delivery, but those of the TMs were generally lower risk methods.

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* See Chapter II, page 86

(i) Co-ordination etc. Variables : SMUs were generally rated worse on all ratings of co-ordination by teachers and mothers; doctors found no general motor handicap in either group at age 7, but at 11 years they judged four SMUs to have "bad co-ordination" and two to have "a condition affecting neurological function". Moreover, at age 11, five SMUs but no TMs had indications of abnormality or clumsiness (2 of balance, 1 of gait, 1 on the finger-nost test, and 1 on the finger-tapping test). More SMUs were rated unsteady walking backwards on a line, were worse at catching a ball, marked fewer squares in one minute, and took longer to pick up 20 matches.

Taken together, these birth factors and co-ordination factors suggest that the "neurological" (in its widest sense) status of the SMUs is worse than that of the TMs.

(j) Laterality : At age 7, SMUs were nearly twice as likely to be left-handed, and more than twice as likely to be mixed-handed, more likely to be left-footed or mixed-footed, and more likely to be mixed-eyed. Thus TMs seem to have established stronger one-sided preferences at an early age. By age 11, mothers reported almost twice as many SMUs left-handed but slightly fewer mixed-handed, and 'hand used for writing' almost reached statistical significance.

SUMMARY OF GROUP COMPARISONS

No single factor has emerged which can justifiably be advanced as a causal factor in all Mathematical underachievement. But high absenteeism, high emotional behaviour ratings, disinterested parents, and potential risk of brain-damage in pregnancy and birth among minorities of the SMU group, suggest that the explanations which have been advanced (e.g. Chapter I, pages 17 - 19) in the literature are all supported by the present study. The fact that no complete group of linked factors reached significance in comparison with the population, taken with the above evidence, supports our view that the SMUs are a heterogeneous group, and that each of these explanatory factors could be a major causal factor for some minority. In particular, there is a statistically defined subgroup of SMUs with a record of pregnancy or birth abnormalities and/or fits or convulsions early in life, who later have learning difficulties more specifically in Mathematics and sometimes in Copying Designs, and who may also have difficulties in co-ordination and non-right or crossed laterality preferences.

The heterogeneity of the SMU group, suggested by the above statistical comparisons, led us to adopt a different kind of approach in order to try to isolate subgroups of actual cases according to hypothesised cuasal factors, although it was obvious from the first that clear subgroup distinctions would be impossible.

INDIVIDUAL SCRUTINY OF THE SMUs

A factor strong enough to be a major cause of underachievement in an individual case, should stand out relative to the general population. Therefore, if we profile each child by 'abnormal' scores on every variable, and cluster the 'abnormal' variables in each profile into sets corresponding to hypothesised causal factors, it might be possible to identify related subgroups of SMUs corresponding to such factors, or perhaps to find links between factors.

For each one of the 142 SMUs, the score on each variable at birth, 7 and 11 years was categorised as 'normal' or 'abnormal' according to its frequency in the population. Thus the highest and lowest (where appropriate) 5 to 10% of numerical scores (educational tests, catches of a ball, square marking, height, weight, etc.), and all minority scores (sensory defects, clumsiness and poor co-ordination, independent schools, high birth order, high ratings on individual BSAG scales, abnormalities of pregnancy and birth, mental retardation, help with backwardness, etc.) were categorised as 'abnormal'. Where there was no clear majority or minority (e.g. social class, parents' occupations) no score was marked 'abnormal'. In this way, a profile of 'abnormal' scores was obtained for each child.

The number of 'abnormal' scores for any individual varied from 4 to 45. Because of the limits set for abnormality (sometimes 10% of scores), the number of variables considered (239) and the number of cases (142), it was obvious that some 'abnormal' scores would arise from chance, and that only clusters of abnormal scores would generally be statistically significant, and worth pursuing psychologically.

Variables were then assigned to one of the following ten categories :

- Educational achievement and ability
- School and schooling (organisation, class size, age at starting, when 'sums' began, etc)
- Family (social class, birth order, parental interest, etc)
- School attendance
- Emotional behaviour (child guidance, BSAG scores, teacher ratings, etc)
- Sensory (sight, hearing, speech)
- Physical (height, weight, head circumference)
- Laterality (handedness, footedness, eyedness)
- Co-ordination (hand control, clumsiness, ball catching, etc)
- Pregnancy, birth and trauma (included smoking in pregnancy, head injury, fits, etc)

Table 3.10 shows the 'abnormal' scores for each child. It is clear from this Table (original underlinings were colour-coded to the ten categories listed above) that detection of groups of factors was not be be accomplished easily. Most children had 'abnormal' scores on all, or most, types of variable; and it is clear that many of the hypothesised causal factors are interlinked, so that it is difficult to separate cause and effect.

At this point we were tempted to abandon this line of enquiry, partly because of its complexity and partly because almost every case seemed to have more than one possible explanation, including, very

TABLE 3.10

SMU'S - ALL "UNUSUAL" SCORES ON VARS. 003 TO 238

CASE NO	VARIABLES WITH UNUSUAL SCORES
1	11, 18, 25, 46, 47, 56, 59, 67, 68, 86, 96, 101, 114, 124, 129, 133, 139, 147, 173 [182 → missing].
2	30, 31, 44, 66, 67, 110, 112, 120, 122, 123, 140, 144, 147, 169, 180, 184, 185, 195, 211, 230, 232.
3	24, 64, 101, 104, 116, 122, 123, 129, 135, 151, 152, 156, 180, 232.
4	11, 27, 28, 30, 32, 42, 43, 45, 64, 66, 68, 88, 89, 95, 96, 102, 103, 104, 110, 135, 140, 144, 145, 146, 148, 186, 195, 196, 197, 206, 211, 214, 217, 221, 232.
5	15, 20, 26, [32 → missing to 85], 104, 110, 112, 132, 139, 160.
6	15, 17, 19, 27, 28, 31, 32, 41, 47, 67, 87, 88, 102, 103, 104, 140, 144, 146, 147, 155, 161, 163, 173, 183, 186, 193, 194, 195, 196, 206, 207, 217, 220, 221, 230, 232, 233, 238.
7	19, 26, 28, 65, 67, 91, 104, 107, 108, 111, 132, 136, 138, 139, 140, 141, 143, 145, 160, 173, 174, 181, 184, 197, 198, 206, 207, 217, 221, 226, 228, 230, 232, 235, 236, 237.
8	22, 31, 45, 107, 108, 110, 111, 112, 136, 137, 138, 145, 146, 147, 212, 218, 232, 236.
9	12, 15, 16, 17, 101, 122, 144, 146, 184, 186, 206, 212, 220, 232, 233.
10	20, 22, 26, 31, 37, 67, 133, 135, 145, 146, 148, 183, 193, 194, 195, 196, 206, 207, 213, 220, 221, 230, 234, 235, 236.
11	5, 15, 16, 30, 32, 36, 39, 46, 63, 65, 66, 67, 90, 93, 94, 101, 102, 103, 104, 107, 108, 111, 114, 115, 126, 136, 143, 144, 145, 146, 147, 149, 154, 157, 160, 163, 183, 186, 197, 198, 213, 226, 228, 230, 236.
12	24, 37, 44, 63, 66, 101, 110, 132, 144, 191, 213, 232, 235, 236.
13	5, 12, 30, 34, 47, 51, 54, 101, 128, 129, 141, 148, 154, 157, 158, 159, 160, 162, 163, 182, 184, 189, 199, 210, 211, 218, 238.
14	5, 44, 64, 65, 66, 67, 88, 91, 122, 182, 232.
15	31, 64, 71, 133, 138, 144, 145, 146, 147, 185, 201, 208, 212, 213, 220.
16	5, 8, 21, 26, 30, 31, 34, 43, 44, 66, 67, 87, 88, 89, 91, 92, 94, 96, 112, 123, 135, 136, 137, 138, 139, 140, 141, 146, 147, 148, 152, 153, 156, 160, 163, 169, 180 [182 → missing].

CASE NO	VARIABLES WITH UNUSUAL SCORES
17	29, 42, 45, 50, 66, 69, 71, 87, 89, 102, 107, 138, 141, 144, 146, 148, 152, 153, 161, 162, 163, 221, 232, 238.
18	18, 19, 26, 28, 43, 44, 63, 64, 91, 101, 110, 114, 122, 123, 132, 143, 144, 146, 148, 153, 184, 208, 232, 238.
19	11, 19, 29, 32, 41, 45, 46, 48, 91, 92, 94, 97, 102, 103, 138, 139, 160, 162, 180, 183, 186, 212, 213, 222, 226, 232.
20	8, 10, 11, 18, 20, 21, 23, 26, 27, 28, 29, 34, 42, 43, 46, 47, 48, 51, 52, 53, 56, 57, 67, 68, 86, 87, 96, 104, 110, 112, 129, 133, 140, 144, 152, 153, 162, 163, 173, 182, 233, 234, 237, 238.
21	18, 34, 44, 56, 57, 62, 136, 138, 144, 155, 158, 182, 184, 232, 233, 235.
22	[2 → missing to 100], 102, 103, 113, 116, 118, 119, 120, 134, 138, 144, 220, 234.
23	15, 16, 17, 20, 30, 34, 55, 56, 57, 68, 101, 116, 122, 123, 130, 139, 148, 182, 184, 185, 191, 193, 194, 195, 196, 206, 207, 217, 221, 233, 236.
24	3, 4, 18, 19, 30, 31, 34, 36, 39, 56, 57, 63, 66, 69, [BSAG missing], 100, 101, 104, 110, 112, 118, 119, 130, 133, 143, 144, 145, 146, 147, 148, 212, 213, 235, 236, 237, 238.
25	18, 30, 34, 45, 48, 102, 103, 104, 122, 130, 136, 143, 144, 146, 182, 233.
26	18, 19, 69, 71, 90, 91, 93, 94, 102, 103, 143, 144, 145, 146, 147, 148, 184, 185, 236.
27	5, 6, 28, 31, 72, 92, 96, 101, 114, 122, 132, 145, 146, 147, 217, 237, 238.
28	11, 12, 17, 18, 19, 20, 24, 26, 30, 31, 44, 59, 82, 83, 86, 88, 89, 92, 94, 107, 111, 112, 126, 129, 135, 136, 138, 144, 146, 148, 152, 153, 155, 156, 159, 160, 163, 164, 165, 173, 180, [182 → missing].
29	12, 29, 30, 31, 68, 87, 89, 95, 102, 103, 107, 111, 122, 123, 135, 136, 137, 138, 139, 144, 145, 146, 147, 148, 151, 152, 153, 161, 163, 173, 183, 184, 193, 194, 195, 196, 206, 207, 217, 221, 232.
30	19, 63, 65, 66, 67, 138, 139, 140, 146, 197, 198, 213, 226, 228, 230, 235.
31	15, 16, 20, 32, 45, 50, 65, 67, 69, 87, 137, 139, 186, 197, 198, [202 → missing].
32	31, 36, 44, 47, 65, 66, 69, 71, 101, 102, 103, 104, 110, 112, 113, 133, 138, 183, 184, 197, 198, 212, 217, 221, 226, 228, 232.
33	17, 43, 44, 56, 63, 122, 123, 133, 137, 145, 148, 153, 183, 184, 234, 237.
34	8, 11, 17, 26, 27, 42, 43, 45, 47, 63, 68, 87, 88, 89, 92, 96, 101, 136, 139, 140, 148, 151, 181, 184, 233.

CASE NO	VARIABLES WITH UNUSUAL SCORES
35	15, 26, 28, 30, 50, 65, 66, 67, 90, 95, 104, 120, 123, 134, 149, 156, 159, 237.
36	15, 17, 39, 40, 47, 65, 72, 95, 102, 103, 110, 112, 114, 115, 169, 170, 171, 181, 232, 233, 234.
37	[2 → missing to 96], 122, 134, 144, 145, 146, [182 → missing].
38	29, 66, 67, 89, 90, 101, 102, 103, 110, 114, 115, 132 (no unusual scores after this).
39	20, 24, 42, 47, 63, 95, 102, 103, 110, 112, 130, 132, 136, 138, 144, 145, 146, 206, 221, 237, 238.
40	15, 16, 19, 20, 22, 66, 81, 82, 90, 103, 228, 237, 238.
41	6, 19, 104, 138, 139, 145, 158, 159, 180, 199, 213.
42	15, 19, 30, 32, 36, 51, 96, 101, 110, 135, 138, 139, 145, 148, 169, 183, 186, 236.
43	45, 52, 65, 66, 67, 69, 71, 100, 101, 104, 108, 116, 155, 182, 197, 198, 226, 236.
44	5, 6, 18, 19, 44, 95, 101, 102, 103, 104, 113, 138, 230, 232, 235, 237, 238.
45	12, 17, 18, 19, 30, 31, 87, 88, 95, 101, 107, 144, 145, 146, 147, 148, 162, 183, 212, 213.
46	12, 136, 212, 232.
47	16, 18, 19, 24, 30, 54, 66, 67, 71, 90, 91, 93, 94, 102, 103, 122, 130, 133, 134, 138, 144, 145, 146, 182, 233, 236.
48	30, 32, 65, 68, 87, 95, 101, 102, 104, 145, 146, 182, 197, 198, 233, 234, 236, 237, 238.
49	15, 16, 26, 39, 67, 72, 90, 93, 101, 130, 133, 149 [182 → missing].
50	19, 44, 65, 66, 71, 135, 143, 151, 220, 226.
51	19, 64, 66, 67, 95, 101, 104, 110, 130, 134, 138, 143.
52	47, 67, 104, 116, 147, 153, 154, 155, 157, 163, 212, 232.
53	18, 24, 31, 55, 67, 68, 95, 96, 107, 108, 110, 111, 112, 114, 130, 132, 138, 143, 144, 146, 149, 184, 193, 194, 195, 196, 206, 207, 221, 230, 235.
54	18, 19, 20, 47, 66, 67, 133, 138, 147, 169, 193, 194, 195, 196, 206, 207, 221, 228, 230, 232.
55	12, 18, 19, 30, 65, 66, 67, 144, 146, 147, 148, 193, 227, 229, 231, 237.

CASE NO	VARIABLES WITH UNUSUAL SCORES
56	26, 28, 35, 36, 45, 54, 55, 59, 66, 89, 135, 156, 160, 163, 183, 186, 195, 196, 197, 206, 232.
57	17, 31, 43, 47, 61, 67, 95, 101, 110, 112, 130, 144, 145, 146, 147, 230, 236.
58	5, 6, 30, 66, 67, 92, 143, 145, 182, 184, 228, 230.
59	8, 31, [32 → 61 missing], 65, 66, 67, 90, 92, 116, 144, 145, 146, 183, 184, 185, 186, 197, 198, 226, 228, 230, 233.
60	12, 15, 16, 25, 30, 31, 32, 61, 103, 104, 114, 115, 122, 123, 132, 143, 183, 184, 186, 201, 235.
61	5, 26, 27, 28, 34, 56, 57, 102, 103, 104, 112, 122, 123, 129, 130, 132, 145, 146, 147, 152, 155, 156, 157, 158, 160, 161, 163, 164, 165, 166, 167 [182 → missing].
62	42, 59, 64, 65, 66, 67, 68, 94, 114, 115, 129, 173, 186, 193, 194, 195, 196, 198, 206, 207, 221, 226, 228, 230, 235, 237, 238.
63	11, 15, 26, 28, 34, 56, 57, 64, 89, 100, 101, 104, 116, 153, 155, 157, 160, 163, 182, 183, 186, 208, 219, 230.
64	5, 8, 15, 32, 43, 48, 59, 90, 96, 100, 101, 110, 112, 129, 138, 160, 169, 170, 186.
65	5, 6, 20, 24, 30, 55, 67, 68, 104, 107, 108, 111, 112, 114, 115, 122, 123, 132, 138, 143, 144, 184, 185, 193, 194, 195, 196, 206, 207, 232.
66	12, 34, 44, 56, 57, 59, 86, 112, 182, 235, 236.
67	19, 71, 144, 145, 146, 147, 148, 182, 199, 209, 214, 233.
68	5, 23, 63, 67, 138, 156, 161, 180, 213, 221, 232, 235, 236.
69	17, 31, 37, 38, 44, 45, 50, 87, 89, 91, 124, 149, 161, 180, 185, 197, 232, 233, 234.
70	8, 31, 67, 95, 100, 101, 104, 114, 115, 130, 145, 146, 154, 189, 228, 230, 232, 233.
71	27, 30, 44, 45, 64, 66, 67, 90, 129, 145, 181, 184, 185, 186, 189, [202 → missing].
72	9, 10, 18, 19, 20, 41, 42, 51, 66, 67, 69, 83, 95, 104, 118, 130, 144, 146, 149, 183, 186, 193, 194, 195, 196, 197, 206, 207, 220, 228.
73	35, 36, 39, 65, 95, 130, 136, 137, 138, 144, 145, 146, 197, 198, 212, 213, 221, 226, 236, 238.
74	19, 65, 66, 67, 104, 123, 137, 138, 143, 145, 147, 197, 198, 230, 232, 233, 234, 235.
75	[missing to 96], 104, 110, 112, 122, 139, 140, 144, 148, 149, 153, 155, 158, 159, 160, 161, 162, 163, 173, 232, 233.

CASE NO	VARIABLES WITH UNUSUAL SCORES
76	19, 26, 48, 64, 65, 66, 67, 132, 133, 145, 146, 230, 237.
77	11, 17, 20, 27, 60, 90, [182 → missing].
78	[missing to 96], 110, 123, 145, 146, 184, 185, 237, 238.
79	[missing to 96], 136, 138, 145, 147, 181, 184, 185, 186, [203 → missing].
80	17, 18, 24, 64, 67, 90, 104, 116, 129, 130, 137, 138, 140, 143, 144, 146, 148, 149, [182 → missing].
81	15, 18, 67, 122, 129, 139, 143, 154, 155, 156, 158, 160, 161, 163, 169, [182 → missing].
82	8, [32 → 87 missing], 182, 212, 217, 232, 233, 234.
83	22, 24, 31, 35, 36, 39, 43, 67, 69, 101, 110, 112, 114, 115, 136, 138, 144, 145, 146, 149, 230, 235.
84	20, 22, 24, 30, 31, 42, 46, 63, 66, 102, 103, 136, 138, 144, 145, 146, 180, 212, 213, 237, 238.
85	8, 17, 47, 66, 71, 110, 112, 130, 146, 149, 230, 235, 236.
86	5, 8, 15, 16, 18, 30, 31, 45, 47, 65, 89, 91, 102, 104, 132, 135, 144, 147, 148, 182, 197, 198, 218, 226, 228, 235.
87	3, 4, 18, 20, 26, 27, 30, 34, 36, 45, 57, 59, 60, 66, 100, 101, 104, 110, 112, 116, 118, 119, 130, 139, 140, 148, 173, 189, 193, 194, 195, 196, 206, 207, 210, 212, 213.
88	8, 9, 10, 18, 38, 45, 113, 114, 115, 138, 151, 217, 235, 236.
89	10, 29, 47, 59, [62 → 86 missing], 89, 91, 94, 123, 208, 213, 228.
90	11, 35, 36, 39, 43, 59, 66, 95, 96, 97, 101, 145, 146, 154, 120, 236.
91	53, 66, 67, 114, 185, 199, 207, 208, 230.
92	16, 19, 22, 30, 34, 47, 56, 57, 110, 112, 114, 115, 135, 151, 182, 212, 235, 236.
93	15, 17, 35, 36, 39, 46, 54, 55, 59, 64, 68, 107, 108, 111, 132, 135, 139, 140, 141, 144, 145, 146, 148 [150 → missing].
94	8, 23, 34, 48, 56, 57, 66, 67, 87, 122, 123, 134, 145, 146, 148, 180, 182, 212, 213, 230, 233.
95	24, 26, 31, 114, 116, 145, 146, 148, 186, 230, 235.

CASE NO	VARIABLES WITH UNUSUAL SCORES
96	19, 20, 26, 45, 67, 96, 101, 110, 112, 113, 114, 115, 139, 140, 144, 145, 146, 147, 180, 181, 184, 197, 198, 211, 212, 222, 235, 236.
97	19, 50, 67, 87, 93, 96, 108, 132, 133, 184, 185, 235.
98	24, 29, 48, 87, 92, 96, 107, 108, 111, 129, 135, 140, 151, 152, 153, 163, 169, 170, 184, 185, 208, 212, 232, 235, 236, 237, 238.
99	32, 37, 43, 45, 65, 67, 87, 88, 89, 92, 93, 104, 149, 182, 184, 186, 197, 198, 230, 235, 236.
100	35, 40, 44, 48, 65, 67, 90, 102, 107, 144, 145, 146, 147, 149, 186, 197, 206, 211, 212.
101	44, 46, 59, 60, 66, 67, 95, 102, 103, 129, 136, 143, 189, 193, 194, 195, 196 [202 → missing].
102	3, 4, 15, 16, 44, 66, 67, 96, 101, 118, 119, 120, 141, 145, 169, 193, 232.
103	18, 26, 27, 45, 47, 65, 67, 71, 72, 104, 107, 108, 111, 139, 140, 185, 197, 198, 208, 214, 221, 222, 226, 230, 232, 236.
104	18, 45, 52, 59, 66, 67, 86, 95, 116, 139, 144, 145, 146, 155, 160, 164, 184, 230.
105	19, 29, 56, 57, 87, 96, 97, 101, 102, 103, 104, 110, 112, 114, 122, 148, 149, 218.
106	8, 10, 16, 25, 29, 31, 38, 43, 45, 56, 66, 71, 72, 89, 122, 128, 135, 137, 138, 139, 140, 141, 142, 152, 153, 161, 173, 182, 183, 184, 185, 208, 220, 230, 234, 235, 236.
107	8, 10, 12, 15, 16, 17, 18, 19, 20, 23, 25, 27, 34, 44, 56, 57, 63, 65, 66, 89, 90, 96, 101, 123, 135, 137, 139, 154, 155, 158, 163, 182, 184, 185, 197, 198, 226, 228, 232.
108	5, 31, 51, 110, 132, 184, 185, 208, 233.
109	11, 12, 15, 19, 23, 26, 30, 38, 44, 48, 59, 60, 66, 87, 89, 92, 95, 114, 115, 147, 148, [182 → missing].
110	[missing to 96] 136, 138, 143, 151, 180, 182, 213, 238.
111	[missing to 96] 116, 138, 182, 183, 186, 206, 237.
112	18, 30, 32, 59, 122, 138, 235.
113	24, 136, 140, 148, 182, 226, 230, 235.
114	5, 15, 18, 32, 37, 66, 67, 86, 95, 107, 108, 111, 130, 133, 137, 145, 183, 191, 217, 230, 233.

CASE NO	VARIABLES WITH UNUSUAL SCORES
115	38, 132, 136, 138, 144, 145, 146, 148, 209, 230.
116	[3-31 missing] 40, 54, [87 to 96 missing] 132, 133, 140, 143, 144, 145, 146, 153, 221.
117	39, 45, 67, 90, 93, 96, 104, 110, 125, 133, 143, 189, 217, 232, 235.
118	10, 18, 19, 22, 30, 64, 66, 137, 140, 143, 145, 146, 149, 181, 213, 235, 236.
119	15, 16, 18, 27, 30, 32, 66, 87, 88, 89, 92, 100, 101, 114, 115, 214, 217, 232, 233.
120	15, 16, 26, 27, 29, 30, 87, 95, 102, 103, 145, 213.
121	15, 19, 34, 43, 45, 55, 57, 65, 66, 67, 68, 95, 100, 101, 134, 138, 143, 152, 153, 155, 158, 163, 173, [182 - 205 missing] 206, 212, 214, 221, 232.
122	8, 10, 26, 27, 31, 47, 51, 56, 67, 89, 91, 96, 102, 103, 104, 110, 112, 123, 140, 145, 153, 154, 161, 180, 186, 213, 230, 232, 235, 236.
123	15, 19, 32, 42, 44, 45, 110, 135, 138, 141, 142, 183, 186, 232, 233
124	19, 34, 35, 56, 57, 59, 60, 66, 95, 110, 112, 120, 132, 133, 134, 135, 144, 145, 146, 147, 182, 184, 232.
125	3, 4, 12, 17, 26, 28, [32 - 86 missing] 89, 91, 92, 93, 94, 118, 119, 122, 123, 139, 155, 157, 162, 163, 197, 208, 210, 232.
126	22, 31, 63, 66, 67, 95, 101, 104, 134, 143, 144, 159, 193, 194, 195, 196, 206, 207, 211, 212, 213, 220, 221, 222, 230, 232, 235, 238.
127	12, 15, 16, 17, 18, 26, 35, 39, 56, 57, 66, 68, 96, 138, 143, 156, 159, 164, 169, 183, 195, 212, 213, 221, 236, 237, 238.
128	18, [32 - 86 missing] 90, 93, 94, 107, 111, 122, 123, 133, 134, 136, 146, 148 [182 → missing].
129	3, 4, 16, 19, 26, 27, 44, 63, 66, 67, 100, 107, 111, 116, 118, 119, 123, 129, 134, 136, 143, 145, 148, 149, [182 → missing].

CASE NO	VARIABLES WITH UNUSUAL SCORES
130	3, 4, 26, 36, 39, 42, 45, 52, 101, 118, 119, 133, 134, 144, 145, 146, 182, 208, 232.
131	27, 28, 35, 39, 72, 91, 92, 93, 102, 103, 122, 140, 145, 208, 211, 232.
132	31, 32, 65, 66, 67, 101, 116, 120, 132, 144, 146, 161, 186, 197, 198, 211, 213, 222, 226, 228, 230, 235.
133	36, 45, 65, 66, 95, 145, [182 → missing].
134	17, 30, 31, 32, 96, 101, 104, 108, 122, 132, 134, 137, 141, 145, 146, 147, 149, 169, 180 [182 → missing].
135	11, 16, 28, 29, 30, [62 → 86 missing] 89, 91, 92, 94, 101, 104, 122, 130, 135, 138, 140, 145, 147, 148, 152, 154, 155, 163, 180, 181, 184, 185, 213, 230, 236.
136	12, 15, 17, 21, 23, 26, 27, 28, 29, 30, 36, 45, 51, 52, 59, 66, 67, 68, 71, 90, 95, 104, 110, 112, 113, 114, 115, 144, 146, 148, 169, 206, 210, 217, 228, 230, 232, 235.
137	17, 42, 46, 66, 68, 94, 116, 145, 211, 233.
138	3, 4, 18, 19, 24, 35, 36, 39, 66, 102, 118, 119, 145, 146, 221, 233, 235.
139	11, 12, 15, 16, 17, 32, 36, 39, 40, 43, 53, 65, 66, 90, 91, 92, 93, 94, 114, 115, 118, 138, 140, 145, 155, 164, 165, 186, 210, 213, 234.
140	16, 24, 30, 36, 42, 47, 90, 123, 129, 154, 183, 189, 208, 230.
141	19, 31, 32, 39, 40, 45, 56, 57, [100 to 117 missing] 145, 148, 152, 183, 186, 193, 194, 195, 196, 201, 206, 207.
142	30, 31, 32, 35, 36, 47, 65, 67 [100 to 117 missing] 127, 130, 139, 144, 154, 173, [182 → missing].
143	15, 16, 17, 19, 59, 87, [100 to 117 missing] 138, 145, 230, 232, 237, 238.
144	[missing to 118] 122, 123, 130, 133, 138, 139, 182, 230.

* These variables are from an earlier coding and do not directly correspond to those in Appendix 2.1

Achievement and Ability; School; Family; Attendance; Behaviour; Sensory; Physical; Laterality; Coordination; Birth etc.; Smoking in Pregnancy commonly, everyday variables seemingly a long way from the neurological causes which would be needed to make a case for the existence of dyscalculia. But it is always difficult to separate out causal variables from effects and concommitant variation. Many of the more sociological variables are well documented as being present in many cases of underachievement without being precise enough to be directly causal. The neurological variations however are likely to be independent and less indicators of general disadvantage. When it is noted that attendance differences were not extreme, behaviour score differences were not extreme, and more SMUs were from non-manual classes, why were 'neurological' (or neurologically-related) factors found in group comparisons?

Since an examination of each of the 142 cases individually remained confusing, it became clear that any pattern present was only likely to be exposed by suitable selection of a subgroup. We therefore decided, once again, to further reduce the size of the group of children under consideration. We reasoned that if we chose those children whose performance in Mathematics was most extreme below their performance in Reading Comprehension, we should be most likely to rule out the more general factors such as poor attendance, parental interest, social background, certain school factors and some motivational factors and emotional factors as primary causes, and gain some insights by studying further the profile of the remaining individuals. Moreover, following the rationale for our choice of the SMU group from the whole group of Mathematics underachievers, we should further isolate specific Mathematical underachievement. Such a group of extremely discrepant Mathematics and Reading Comprehension scorers was chosen by taking the "worst" cases of Mathematics underachievement (3 standard errors below expectation based on ability) yet who were less than 1 s.e. below expected score on RC (8 cases), and also the "best" cases of Reading achievement (2 s.e.s above expected score based on ability) yet who were more than 2 s.e.s below expected score for Mathematics (6 cases). Table 3.11 gives "abnormal" score variables for each of these 14 children.

From Table 3.11 we can see that, as expected, most poor attenders and highly emotional children in the SMU group have been excluded. Common 'abnormal' variables among the 14 children of this special group are :

pregnancy or birth abnormalities or head injury (10 cases)
poor co-ordination variables (14 cases)
deviant laterality (8 cases; 2 others mixed-handed at age 7)
extremes of size (9 cases).

Of these variables, all but the latter support the dyscalculia hypothesis in that all have been linked in theory with abnormalities of brain organisation. (In fact, even physical size is connected with brain activity since there are brain centres which control physical growth rates). The results from these 14 cases have a further factor which may have some import : the fact that 11 of them are girls; both deviant laterality and poor co-ordination were more common among boys in the NCDS data.

TABLE 3.11

SMU*'S : ALL "UNUSUAL" SCORES ON VARS. 003 TO 238

CASE NO	SEX	MATHS SCORE AT AGE 7	TR AT AGE 7	MATHS SCORE AT AGE 11	TR AT AGE 11	VARIABLES WITH ABNORMAL OR EXTREME SCORES
10	F	7	Average	0	Below av.	20, 22, 26, 31, 37, 67, 133, 135, 145, 146, 148, 183, 193, 194, 195, 196, 206, 207, 213, 220, 221, 230, 234, 235, 236.
80	F	4	V. Bad	0	Below av.	17, 18, 24, 64, 67, 90, 104, 116, 129, 130, 137, 138, 140, 143, 144, 146, 148, 149 [182 → missing]
116	F	missing	missing	10	Below av.	[missing to 31] 40, 54 [87 to 96 missing] 132, 133, 140, 143, 144, 145, 146, 153, 221.
8	F	4	Average	10	Above av.	22, 31, 45, 107, 108, 110, 111, 112, 136, 137, 138, 145, 146, 147, 212, 218, 232, 236.
48	M	2	Average	7	Average	30, 32, 65, 68, 87, 95, 101, 102, 104, 145, 146, 182, 197, 198, 233, 234, 236, 237, 238.
87	F	8	Average	3	Below av.	3, 4, 18, 20, 26, 27, 30, 34, 36, 45, 57, 59, 60, 66, 100, 101, 104, 110, 112, 116, 118, 119, 130, 139, 140, 148, 173, 189, 193, 194, 195, 196, 206, 207, 210, 212, 213.
12	F	5	Above av.	6	Below av.	24, 37, 44, 63, 66, 101, 110, 132, 144, 191, 213, 232, 235, 236.
30	M	3	Below av.	7	Below av.	19, 63, 65, 66, 67, 138, 139, 140, 146, 197, 198, 213, 226, 228, 230, 235.
74	F	3	Average	8	Below av.	19, 65, 66, 67, 104, 123, 137, 138, 143, 145, 147, 197, 198, 230, 232, 233, 234, 235.
2	F	8	Average	12	Average	30, 31, 44, 66, 67, 110, 112, 120, 122, 123, 140, 144, 147, 169, 180, 184, 185, 195, 211, 230, 232.
52	F	7	Average	9	Below av.	47, 67, 104, 116, 147, 153, 154, 155, 157, 163, 212, 232.
54	F	6	Average	8	Average	18, 19, 20, 47, 66, 67, 133, 138, 147, 169, 193, 194, 195, 196, 206, 207, 221, 228, 230, 232.
28	M	2	V. Bad	4	V. Bad	11, 12, 17, 18, 19, 20, 24, 26, 30, 31, 44, 59, 82, 83, 86, 88, 89, 92, 94, 107, 111, 112, 126, 129, 135, 136, 138, 144, 146, 148, 152, 153, 155, 156, 159, 160, 163, 164, 165, 173, 180 [182 → missing].
88	F	3	Below av.	9	Below av.	8, 9, 10, 18, 38, 45, 113, 114, 115, 138, 151, 217, 235, 236.

A DYSCALCULIA SYNDROME?

On page 130 of this Chapter we asked if we could identify a group of specific Mathematical underachievers who were relatively free of social disadvantage, emotional disadvantage, adverse educational factors, etc., but who were characterised by 'neurological' factors. The group of 14 children just identified do seem to form such a group, with characterising neurological factors consisting of pregnancy or birth abnormalities or head injury, poor co-ordination, and deviant laterality.

Is there, then, a 'dyscalculia syndrome' typified by this group? If so, is it so rare that we can produce only 14 cases out of 14,000 children studied. Is dyscalculia a unitary condition after all?

Firstly, not all the 14 cases showed all the 'neurological' indicators. Although all showed co-ordination levels which were poor compared with the population, these were not necessarily outstandingly poor in themselves, and different aspects of co-ordination were highlighted for different individuals, with teachers' ratings or "poor physical co-ordination" and doctors' ratings of "walking backwards on a straight line" the most common. Similarly, the pregnancy and birth abnormalities covered a wide range of variables; and only eight children showed deviant laterality variables (with two others late to develop a hand preference). From our discussion of our concept of dyscalculia, this situation is to be expected. The group of 14 does represent a rather extreme group, and for this reason we might expect 'neurological' symptoms to be more prominent than in a less extreme group of suspect dyscalculics. We might expect that any "neurological impairment", although mild enough to spare general ability and Reading, would be severe enough in some of these cases to affect not only Mathematics but also some aspects of co-ordination, and the organisation of laterality preferences.

Secondly, we have already noted that in defining Mathematical underachievers (as in May's work) only approximately $^2/_3$ of the population was considered, at the top end of the ability range. In defining SMUs, a further reduction was made by excluding those Mathematical underachievers who were also below 1 s.e. below expectation in Reading Comprehension (RC) - a reduction by a factor of 2. The SMU group was further reduced by a factor of 10 when we defined our special group of 14 in terms of discrepancies between Mathematics and RC. Thus, whilst it is true to say that we have found only 14 relatively 'pure' and 'extreme' cases in 14,000, it is also clear that we might have discarded as many as 350 'severe' Mathematical underachievers, some of whom may well have shown similar characteristics in conjunction with other factors which tended to conceal their effect.

EVALUATION OF OUR NCDS DATA INVESTIGATION

Given the methodological difficulties of this type of investigation (see Chapter I), we consider that a good case has been made for the implication of neurological factors in some cases of severe Mathematical underachievement; and hence for the validation of the concept of dyscalculia. Evidence comes not only from our isolation of a small group of children displaying a fairly consistent set of neurological indicators, but also from the comparisons of the SMU group with the total population, with a group of similar ability and with the top-scoring Maths group. In all of these comparisons, 'neurological' factors were more prevalent or significantly more prevalent in the SMU group. Moreover, 'neurological' factors also appeared in the set of best predictors of Mathematics underachievement at age 11 from variables at ages 7 or birth.

Bearing in mind the limitations of the NCDS battery which was not designed with this research in mind, the results encourage further investigation and give some directions for this further work.

These are taken up in the next Chapter, where the pointers of the NCDS study are integrated into our study of individual school children.

APPENDIX 3.1

DISTRIBUTION OF SCORES ON ABILITY AND ACHIEVEMENT TESTS AT AGE 11

FIGURE 3.1.1 : TOTAL ABILITY SCORES

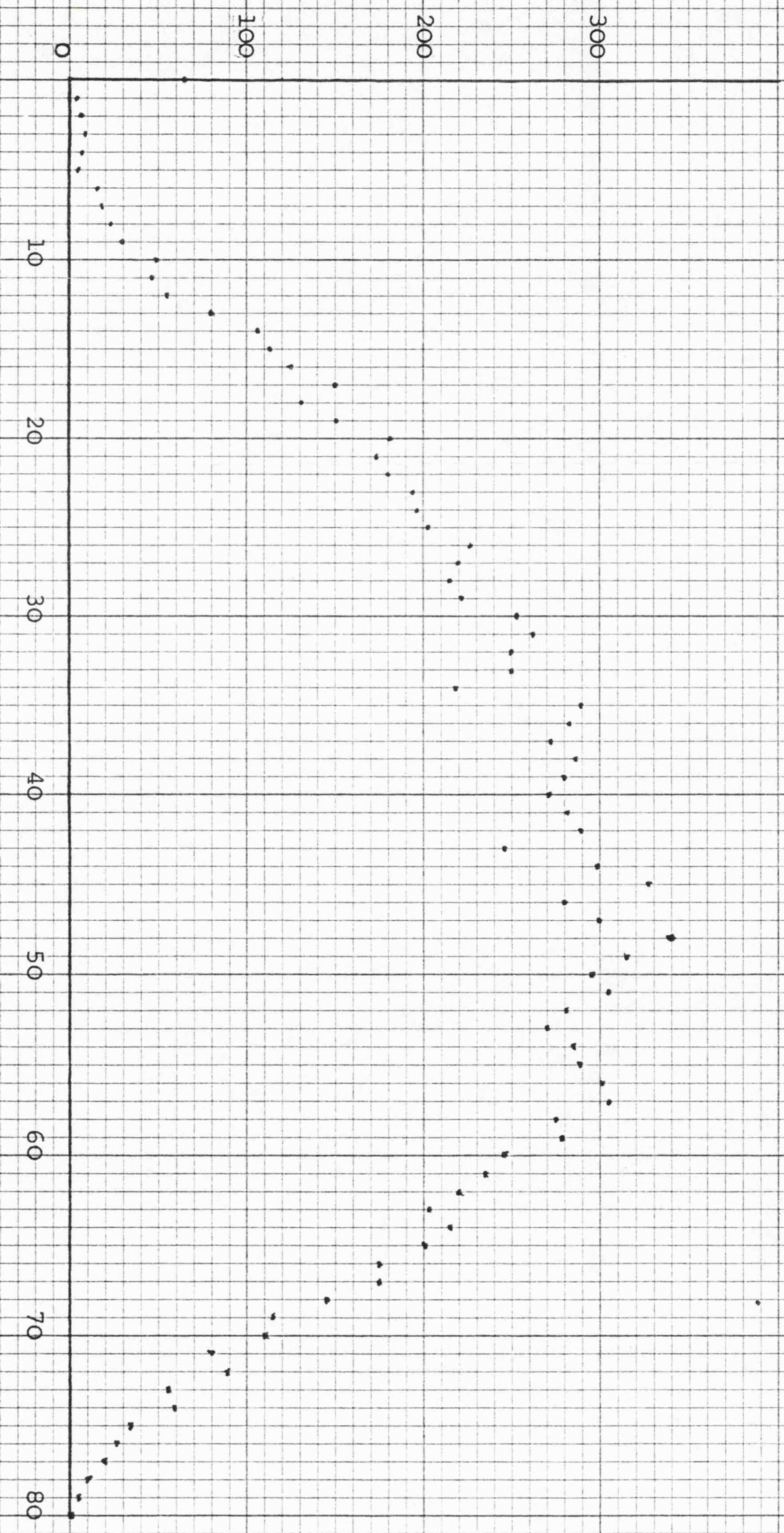


FIGURE 3.1.2 : VERBAL ABILITY SCORE

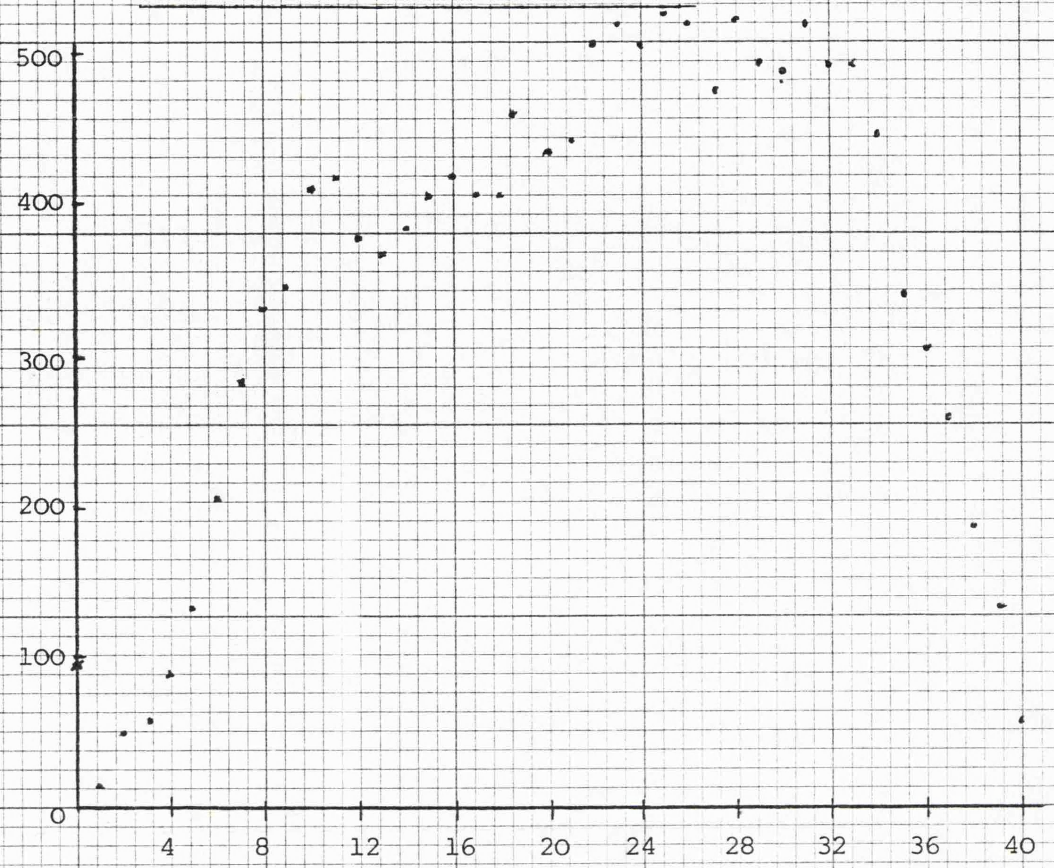


FIGURE 3.1.3 : NON-VERBAL ABILITY SCORES

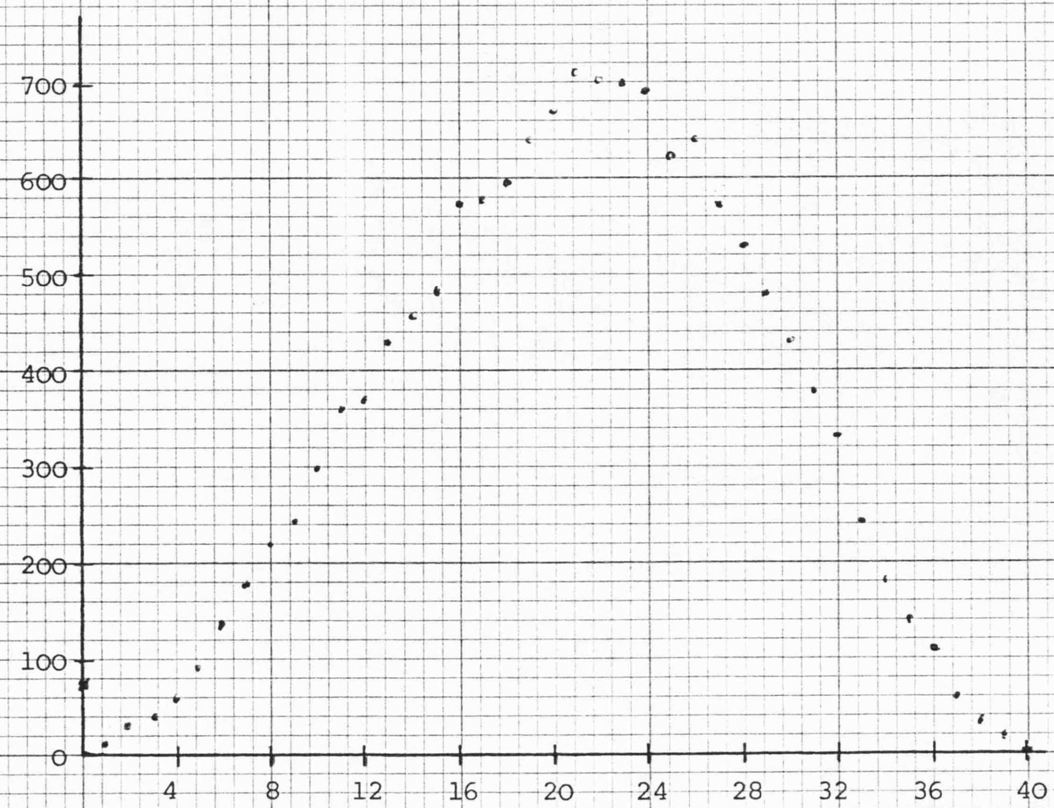


FIGURE 3.1.4 : MATHEMATICS TEST SCORES

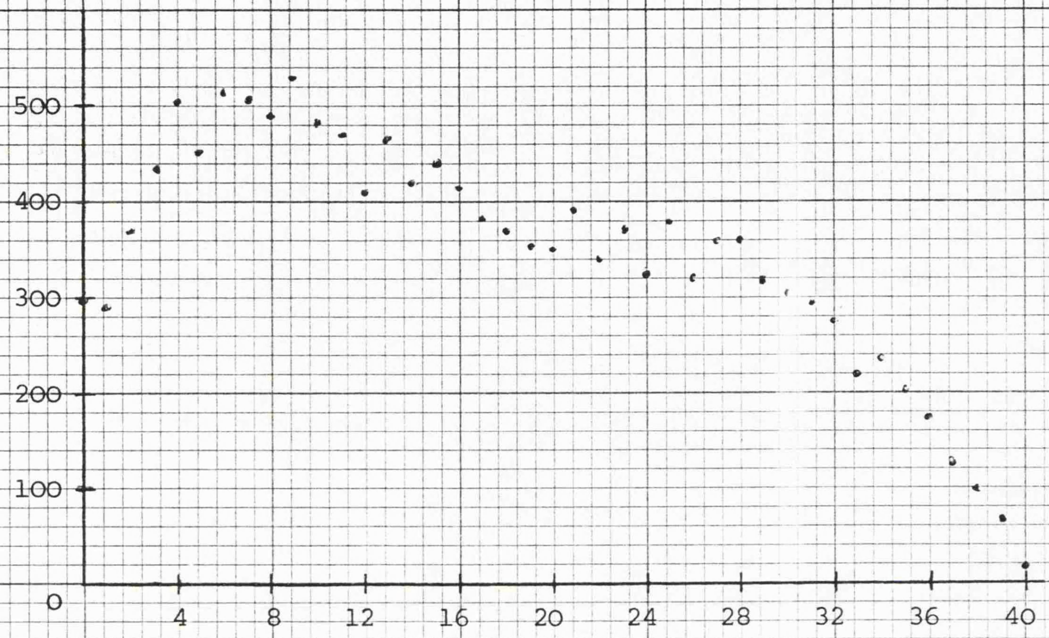
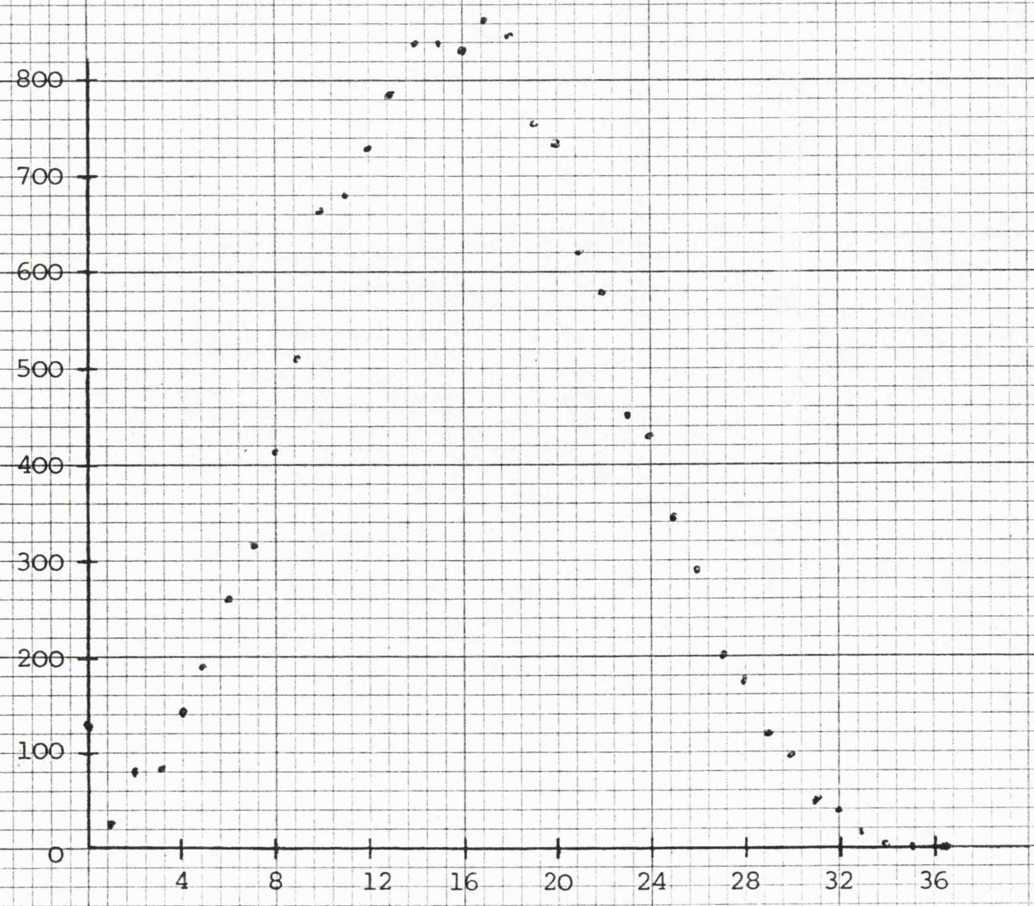


FIGURE 3.1.5 : READING COMPREHENSION TEST SCORES



<u>APPENDIX 3.2</u>

ACHIEVEMENT RECORD OF SMU GROUP

CASE NO	TOTAL ABILITY SCORE	MATHS						READING					
		AGE 7		AGE 11		AGE 16		AGE 7		AGE 11		AGE 16	
		SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP
1	46	3		5	-13.2	5	- 8.5.	18		13		18	-8.3.
2	59	8		12	-13.0	3	-14.4..	30		26		25	-5.3.
3	52	6		7	-14.3	8	- 7.3	29		16		29	+0.8
4	71	8		17	-14.2	-		28		22		-	
5	60	3		11	-14.5	15	- 2.7	29		19		29	-1.6
6	63	6		14	-13.1	18	- 0.6	30		26		33	+1.5
7	57	4		11	-12.9	5	-11.8..	26		18		25	-4.7
8	69	4		10	-20.2	11	- 9.5	30		25		32	-1.4
9	63	4		11	-16.1	-		23		19		-	
10	67	7		0	-29.1	11	- 8.9.	30		19		26	-6.8.
11	67	8		15	-14.1	9	-10.9..	27		25		32	-0.8
12	60	5		6	-19.5	16	- 1.7	29		19		30	-0.6
13	53	2		3	-18.9	9	- 6.6.	28		17		24	-4.4
14	54	6		6	-16.4	10	- 5.9.	27		17		21	-7.7
15	70	5		18	-12.7	18	- 2.8	30		27		31	-2.7
16	43	2		3	-13.7	7	- 5.6.	8		13		25	-0.3
17	40	4		2	-13.1	4	- 7.7.	22		14		29	+4.6
18	39	6		2	-12.6	5	- 6.4.	28		18		27	+2.9
19	49	4		5	-14.8	8	- 6.4.	29		14		23	-4.2
20	59	4		11	-14.0	9	- 8.4.	20		22		31	+0.7
21	60	5		12	-13.5	9	- 8.7.	29		23		29	-1.6
22	56	-		9	-14.4	8	- 8.5.	-		21		26	-3.4
23	47	2		4	-14.7	10	- 3.8	25		14		25	-1.6
24	71	9		17	-14.2	17	- 4.1	30		25		30	-4.0
25	63	8		14	-13.1	15	- 3.7	27		22		30	-1.5
26	36	3		0	-13.1	-		22		11		-	

CASE NO	TOTAL ABILITY SCORE	MATHS						READING					
		AGE 7		AGE 11		AGE 16		AGE 7		AGE 11		AGE 16	
		SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP
27	62	5		11	-15.5	-		30		25		-	
28	43	2		4	-12.7	-		11		21		-	
29	41	0		3	-12.6	6	- 6.0.	15		13		25	+0.3
30	62	3		7	-19.5	-		28		18		-	
31	58	7		11	-13.5	13	- 4.1	27		22		30	0.0
32	47	5		6	-12.7	6	- 7.8.	30		16		32	+5.4
33	48	6		4	-15.3	0	-14.1..	29		14		21	-5.9.
34	48	3		4	-15.3	-		18		16		-	
35	59	2		9	-16.0	17	- 0.4	24		22		30	-0.3
36	53	5		9	-12.9	-		25		18		-	
37	67	-		16	-13.1	17	- 2.9	-		21		28	-4.8.
38	53	3		9	-12.9	9	- 6.6.	16		15		29	+0.6
39	70	5		14	-16.7	3	-17.8..	28		23		30	-3.7
40	56	5		8	-15.4	23	+ 6.5	26		16		26	-3.4
41	49	4		7	-12.8	12	- 2.4	26		15		28	+0.8
42	49	2		4	-15.8	4	-10.4..	29		19		23	-4.2
43	49	5		6	-13.8	8	- 6.4.	21		14		20	-7.2.
44	54	3		8	-14.4	10	- 5.9.	25		19		29	+0.3
45	74	2		20	-12.8	24	+ 2.0	30		27		32	-3.0
46	49	3		7	-12.8	18	+ 3.6	29		19		34	+6.8
47	65	1		12	-16.1	11	- 8.3.	22		22		31	-1.2
48	64	2	-26.6	7	-20.6	13	- 6.0.	16		20	-2.1	31	-0.9
49	53	5	-16.9	9	-12.9	-		26		15	-3.9	-	
50	50	3	-17.3	7	-13.3	10	- 4.7	26		17	-1.0	24	-3.5
51	52	6	-15.3	6	-15.3	-		23		19	+0.4	-	
52	53	7	-14.9	9	-12.9	12	- 3.6	29		25	+6.1	31	+2.6
53	63	4	-23.1	13	-14.1	21	+ 2.4	30		23	+1.2	34	+2.5
54	55	6	-16.9	8	-14.9	8	- 8.2.	28		25	+5.5	29	-0.1
55	43	2	-14.7	4	-12.7	10	- 2.6	25		12	-4.0	25	-0.3
56	45	6	-11.7	5	-12.7	15	+ 1.8	28		18	+1.4	29	+3.0
57	70	7	-23.7	14	-16.7	15	- 5.8.	30		25	+1.2	32	-1.7
58	47	8	-10.7	6	-12.7	6	- 7.8.	21		14	-3.2	27	+0.4

CASE NO	TOTAL ABILITY SCORE	MATHS						READING					
		AGE 7		AGE 11		AGE 16		AGE 7		AGE 11		AGE 16	
		SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP
59	67	6	-21.8	11	-18.1	12	- 7.9.	30		19	-4.0	31	-1.8
60	50	2		5	-15.3	-		5		15	-3.0	29	+1.5
61	65	5		14	-14.1	-		28		25	+2.6	-	
62	51	3		7	-13.8	7	- 8.0.	27		16	-2.3	29	+1.2
63	47	4		5	-13.7	11	- 2.8	22		14	-3.2	27	+0.4
64	57	6		11	-12.9	3	-13.8..	21		21	+0.9	26	-3.7
65	61	8		13	-13.0	6	-12.0..	27		23	+1.8	32	+1.1
66	47	5		5	-13.7	6	- 7.8	25		14	-3.2	19	-7.6.
67	39	6		2	-12.6	-		29		12	-2.8	-	
68	50	3		6	-14.3	9	- 5.7.	25		22	+4.0	30	+2.5
69	56	3		8	-15.4	22	+ 5.5	15		23	+3.2	35	+5.6
70	66	7		16	-12.6	11	- 8.6	30		23	+0.3	28	-4.5
71	45	2		5	-12.7	-		19		19	+2.4	-	
72	62	4		11	-15.5	-		26		18	+3.5	-	
73	65	-		15	-13.1	22	+ 2.7	-		24	+1.6	33	+0.8
74	60	3		8	-17.5	12	- 5.7.	27		28	+7.1	33	+2.4
75	39	-		2	-12.6	3	- 8.4.	-		19	+4.2	30	+5.9
76	65	3		11	-17.1	9	-10.3..	20		21	-1.4	27	-5.3
77	53	4		7	-14.9	8	- 7.6.	29		15	-3.9	25	-3.4
78	64	-		13	-14.6	-		-		20	-2.1	-	
79	45	-		5	-12.7	-		-		13	-3.6	-	
80	63	4		0	-27.1	-		-		19	-2.8	-	
81	49	6		6	-13.8	-		26		17	+0.7	-	
82	54	7		9	-13.4	23	+ 7.1	26		17	-2.2	33	+4.3
83	68	7		13	-16.7	23	+ 2.8	30		20	-3.2	32	-1.1
84	68	8		12	-17.7	16	- 4.2	30		24	+0.8	33	-0.1
85	62	6		11	-15.5	-		25		18	-3.5	-	
86	56	8		3	-20.4	-		29		19	-0.8	-	

CASE NO	TOTAL ABILITY SCORE	MATHS						READING					
		AGE 7		AGE 11		AGE 16		AGE 7		AGE 11		AGE 16	
		SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP	SCORE	DISCREP
87	55	3		9	-13.9	-		27		24	+4.5	-	
88	61	6		12	-14.0	-		26		18	-3.2	-	
89	65	3		13	-15.1	-		25		22	-0.4	-	
90	54	6		9	-13.4	14	- 1.9	27		17	-2.2	27	-1.7
91	55	2		8	-14.9	15	- 1.2	29		17	-2.5	25	-4.1
92	41	4		3	-12.6	2	-10.0.	24		14	-1.4	26	+1.3
93	43	5		4	-12.7	7	- 5.6	17		16	0	20	-5.3
94	43	4		3	-13.7	18	+ 5.4	30		15	-1.0	30	+4.7
95	70	4		12	-18.7	-		28		27	+3.2	-	
96	48	5		5	-14.3	8	- 6.1.	25		19	+1.6	24	-2.9
97	51	3		7	-13.8	-		25		18	-0.3	-	
98	60	5		9	-16.5	-		27		18	-2.9	-	
99	77	4		16	-18.3	7	-15.9..	27		25	-0.9	26	-9.9
100	58	5		11	-13.5	13	- 4.1	29		22	+1.7	29	-1.0
101	60	4		11	-14.5	7	-10.7..	23		18	-2.9	22	-8.6.
102	53	4		7	-14.9	16	+ 0.4	26		15	-3.9	27	-1.4
103	67	5		16	-13.1	9	-10.9..	28		22	-1.0	23	-9.8..
104	48	5		2	-17.3	8	- 6.1.	28		17	-0.4	26	-0.9
105	49	4		7	-12.8	9	- 5.4.	14		14	-3.7	19	-8.2
106	57	-		11	-12.9	8	- 8.8.	-		23	+2.9	26	-3.7
107	58	5		11	-13.5	14	- 3.1	30		17	-3.3	28	-2.0
108	47	2		2	-16.7	7	- 6.8.	26		13	-4.2	23	-3.6
109	50	-		5	-15.3	-		-		22	+4.0	-	
110	59	-		11	-14.0	-		-		22	+1.4	-	
111	55	8		10	-12.9	15	- 1.2	26		22	+2.5	31	+1.9
112	50	4		3	-17.3	10	- 4.7	29		14	-4.0	23	-4.5
113	58	3		11	-13.5	12	- 5.1	22		21	+0.7	32	+2.0
114	70	7		18	-12.7	16	- 4.8	29		21	-2.8	26	-7.7.
115	74	-		10	-22.8	-		-		22	-3.0	-	

CASE NO	TOTAL ABILITY SCORE	MATHS AGE 7 SCORE	MATHS AGE 7 DISCREP	MATHS AGE 11 SCORE	MATHS AGE 11 DISCREP	MATHS AGE 16 SCORE	MATHS AGE 16 DISCREP	READING AGE 7 SCORE	READING AGE 7 DISCREP	READING AGE 11 SCORE	READING AGE 11 DISCREP	READING AGE 16 SCORE	READING AGE 16 DISCREP
116	54	7		6	-16.4	17	+ 1.1	24		17	+2.2	30	+1.3
117	64	2		10	-17.6	-		29		22	-0.1	-	
118	47	2		6	-12.7	13	- 0.8	29		17	-0.2	29	+2.4
119	47	2		6	-12.7	11	- 2.8	27		18	+0.8	29	+2.4
120	56	3		7	-16.4	1	-15.5..	29		19	-0.8	29	-0.4
121	60	5		11	-14.5	13	- 4.7	30		19	-1.9	25	-5.6.
122	46	4		5	-13.2	-		25		15	+1.9	-	-
123	70	4		16	-14.7	12	- 8.8	29		26	+2.2	32	-1.7
124	60	6		12	-13.5	15	- 2.7	26		22	+1.1	31	+0.4
125	58	3		10	-14.5	5	-12.1..	30		19	-1.3	28	-2.0
126	58	5		11	-13.5	5	-12.1..	24		22	+1.7	32	+2.0
127	43	4		4	-12.7	5	-10.6..	27		18	0	30	+4.7
128	44	4		3	-14.2	4	- 8.9.	29		19	+1.3	29	+3.4
129	71	6		16	-15.2	16	- 5.1	26		20	-4.1	25	-9.0.
130	57	5		11	-12.9	11	- 5.8.	23		16	-4.1	31	+1.3
131	62	4		14	-12.5	13	- 5.4.	30		23	+1.5	31	-0.2
132	61	3		13	-13.0	6	-12.0..	29		17	-4.2	26	-4.9.
133	65	9		13	-15.1	-		30		26	+3.6	-	
134	43	2		4	-12.7	6	- 6.6.	17		17	+1.0	25	-1.3
135	60	5		12	-13.5	16	- 1.7	24		17	-3.9	32	+1.4
136	63	5		14	-13.1	7	-11.7..	28		20	-1.8	24	-7.5.
137	59	5		11	-14.0	14	- 3.4	28		17	-3.6	26	-4.3
138	52	9		8	-13.3	-		28		18	-0.6	-	
139	44	7		4	-13.2	-		30		17	+0.7	-	
140	60	8		11	-14.5	21	+ 3.3	30		18	-2.9	31	+0.4
141	61	5		13	-13.0	-		29		18	-3.2	-	
142	54	-		9	-13.4	-		-		20	+0.8	-	

SMUs defined at age 11. Maths score < 2 s.e.s below expected.
Reading score not more than 1 s.e. below expected.

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CHAPTER IV

OUR INITIAL CASE STUDIES

The first part of this chapter is devoted to the design of the test battery for use in case studies of children in local schools. Then follows a description of the initial case studies and their results.

We now turn to our complementary investigation of the concept of dyscalculia through case studies in local schools. This part of the investigation was begun before analysis of the NCDS data had reached its final stage, and at this stage the two investigations were running in parallel.

Our first requirement for the individual studies of local children was the construction of a battery of tests appropriate to such an investigation.

THE TEST BATTERY

At the outset in our consideration of suitable tests for use in this investigation, three major limitations were imposed :

(1) Most "Medical" tests could not be used, since administering them would need medical qualifications. This ruled out, for example, the search for certain 'soft' neurological signs such as abnormal reflexes, which are sometimes reported in cases of reading difficulty.

(2) "Family" information was very limited and had to be confined to informal details given by the individual children. Although the local schools were interested in our investigation and often extremely cooperative they were reluctant and in some cases unwilling to involve parents and families. Had this been a main focus of the study, it is likely that some schools could have been prevailed upon to help in this way, but it was not possible to overcome the difficulties within the scope of the present study. This meant that family background and early history were usually not available to us. This was rather disappointing in view of the possible implication of perinatal variables in the aetiology of learning disorders, and is an area warranting further study.

(3) Time and resources were strictly limited. The resource limitation ruled out, for example, the use of brain scans (in a preliminary investigation such as this, their use would arguably be premature, anyway), but also had implications for the tests ultimately chosen (see p.168). The most serious time limitation was imposed by the participating schools, who were rightly concerned that children should not miss too many lessons. This meant that complete major test batteries such as the whole of the BAS scales could not be used.

Our first analysis of the NCDS data, and May's [1] work on correlates and predictors of mathematical under-achievement (see Chapter III), had suggested that under-achievement in Mathematics might be related to :

(a) Variables underlying poor performance on the copying designs test : coordination variables, directional discrimination, or poor grasp of relationships.

(b) Laterality variables, particularly non-right hand preference and crossed laterality of hand and eye.

(c) perinatal variables, particularly those found to be related to increased risk in the Perinatal Mortality Survey.

(d) Coordination variables, which showed up increasingly from age 7 to age 16.

A survey of the literature on learning disorders, particularly disabilities such as dyslexia in which the disorder is more specific to one area, also suggested laterality variables, coordination, and perinatal variables as possible correlates. The prospective study of Minimal Brain Dysfunction by Chen and Nichols [2] also suggested that directional discrimination is a good predictor of learning disorders. Writers studying Gerstmann syndrome parallels with Mathematical difficulties [3] [4] have indicated poor finger and directional discrimination as being implicated. Other writers, such as Kleuve [5] have linked some poor Mathematical performances with memory deficits. Abnormal profiles of abilities on well-established test batteries, such as the WISC, have been postulated for learning-disabled groups, but seldom found, possibly due to the heterogeneity of the groups used.

The limitations noted above, together with our survey of the literature, and the first analysis of the NCDS data, suggested that a starting point for our test battery might be :-

(a) a set of basic ability tests, such as the WISC or BAS, to obtain a pattern of abilities

(b) laterality tests of hand, eye, foot and ear preferences

(c) tests of right-left discrimination, and finger discrimination

(d) tests of memory, particularly short-term memory

(e) tests of coordination and balance.

Preliminary contact with local schools (see below) soon established that because they had little data on record, in many cases we should also need to assess :

(f) the child's overall (general) ability (possibly using (a))

(g) the child's functioning in Mathematics relative to other areas.

Clearly this set of requirements had to be reduced in order to comply with time limits and resources ; this reduction was achieved in the following ways.

(f) and (g) were both accounted for by using the short forms of AH3 [6]. This test consists of timed reasoning tests using verbal, numerical, and perceptual materials separately, so giving an overall measure of reasoning capacity*, together with differences in facility* in handling the three types of material - in particular any specific lack of facility with numerical material.

**(e) was represented by "walking backwards on a straight line", taken from the NCDS tests. This was the NCDS test of its type most closely associated with Mathematics under-achievement. In addition, one of the laterality tests, hopping on preferred foot, could also be used for assessment of balance.

(d) was represented by one of the tests from (a) - namely, the oral-verbal versions of forwards- and backwards-digit span measures. The latter of these also detects abnormalities of temporal ordering in short-term memory.

(c) was represented by a simple crude test of left and right in which the child was asked to point to areas on the left or right of his own body.

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* Although not themselves measures of 'general ability' and 'mathematical functioning' these tests do correlate with 'general ability' [6] and do give comparisons of mathematical functioning with verbal and perceptual functioning as manifest by facilities in handling these types of material

** This test was omitted from our first set of case studies

(b) used two or three of the most consistent and reliable preference measures for hand, foot and eye, and was based on the set of measures used in the NCDS. Compatability with the NCDS data, and consistency and reliability of measures reported in the literature dictated this choice.

(a) was represented by three of the four tests* from the British Ability Scales [7] which are recommended as a minimum basis for I.Q. assessments, namely : Matrices, Similarities and Digit Span. These tests are among the best representatives of three basic abilities (Non-verbal, Verbal and Memory), all of which are vital to adequate Mathematical performance. The British Ability Scales, rather than the WISC, were chosen for two reasons : they were constructed for use with, and normed on, British children, and the writer was a registered user as a member of the British Psychological Society.

This set of tests made up the basic test battery used in our case studies; it took approximately one and a half hours per child to administer. All the tests except AH3 were administered individually; AH3 was administered to groups of various numbers of children.

Detailed descriptions of the tests together with administration procedures, where these are not described in appropriate test manuals, are given in Appendix 4.1.

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* The fourth test is Speed of Information Processing.

ORDER OF ADMINISTRATION

The order of administration of the tests was as follows :-

(a) AH3 to a small group of children nominated as possible Mathematics underachievers. This was used as a screening test to ensure that children in the study were of adequate intelligence and usually also indicated that they had specific difficulty with numerical material (but see Chapter IX).

By administering this test first, the children were introduced to us in a group situation, which was thought to be less threatening to them than the one-to-one situations of the later tests.

(b) Laterality tests. These tests were found to "break the ice" in the initial one-to-one testing situation. This was an important contribution, since there was no time allowed for establishing rapport with the child prior to testing.

Most of the children were found to relax considerably during these tests, and were likely to be more forthcoming thereafter.

(c) Walking backwards on a line. Another activity test which followed the laterality tests naturally, and which again helped the children to relax.

(d) Knowledge of left and right. This was the last of the 'activity' tests, which were clearly perceived by the children as being less threatening, less related to academic standards, and less demanding of mental effort than conventional school tests. By grouping the "activity" type tests together in this way, the children would also be less likely to guess their objectives, and so influence our results.

(e) Digit Span Memory Tests. These were administered before the Similarities and Matrices tests and continued to keep the children at ease. They appeared to be some way from "school tests", and confidence was built up by beginning with a simple pair of numbers to be repeated. This also helped to develop rapport in the one-to-one situation.

(f) Similarities. Perhaps the most difficult test from the children's viewpoint, requiring thought and an oral response.

(g) Matrices. This was administered last so that the child would not be under time pressure to go on to the next test. After completing the practice items the children were left to work through the Matrices Test booklets at their own speeds.

THE INITIAL STUDY

The Subjects

The aim of this part of our study was to locate children in local schools whose Mathematical performance relative to ability was similar to that of the SMU group in our analysis of the NCDS data. In practice this proved quite a difficult task as the degree of underachievement required was a stringent one, and the problem of locating such children in real life raised a number of problems.

Only about 1 in 100 of the NCDS children had belonged to the SMU group ; that is, many junior schools in that study had supplied no children to the SMU group. This also proved to be our experience : a direct approach to eight local jnuior schools provided a single child, aged 9, whom teachers considered to be having difficulties fairly specific to Mathematics, but no children in the appropriate age group (top juniors) for direct comparison with the SMU children.

After obtaining permission from the LEAs we had written to all schools circulated with the School of Education (Bath) newsletter to ask for any likely pupils. This concentrated mainly on secondary schools, and was followed up by a direct approach to some junior schools (mentioned above) and to some comprehensive schools.

It was, of course, clear that neither time nor resources would allow us to test all the children necessary to locate a viable sample of specific mathematical under-achievers in a similar way to the NCDS procedures, which was why we had decided to ask for nominations of suitable children from the teachers who had contact with the children.

Age of children was another problem. Junior schools had two distinct advantages for our purposes ; the SMU children had been chosen from NCDS data obtained when they were top juniors hence direct comparisons would be possible, and also teachers would be likely to know such children, their academic strengths and weaknesses as well as any adverse circumstances. On the other hand, comprehensive schools would be more likely to have appropriate children because of their large intake. They should also have the children's JVR scores from their last year in junior school, and thus the potential to find discrepancies between Mathematics achievement and the JVR score as a measure of ability. However, because of subject specialization by teachers, meeting the requirement that the children nominated should be doing better in other subjects would involve the teachers in a lot of extra work - as we found when we were shown all the different records for each child and attempted to interpret these in terms of achievement in various subject areas. (How should "struggling" in the TopSet for English compare with "adequate" in the Bottom Set for Mathematics?).

Another difficulty in practice, though not in theory, was the distinction between "under-achievement" and "lack of achievement". Children who could not do Mathematics were well-known to Mathematics teachers, but such children were usually of low ability and tended to do badly in other subjects also. Whereas children who were "average" at Mathematics were often not considered for nomination, whatever their general ability levels. This changed dramatically in the case of sixth-formers ; here the results of 'O'level examinations indicated general ability level and emphasized differences between subject areas, so that some children were manifestly underachieving specifically in Mathematics.

Some schools left it to us to find suitable children after supplying us with a list of JVR scores and the scores on a school

Mathematics test, administered in the childrens' first term at secondary school. This ensured that, relative to their year group at their school children identified in this way were mathematical underachievers, but gave no comparison with other subject areas.

Whatever the method used for selection or nomination, all the children included in our case studies were under-achieving in Mathematics. Since the expected incidence of suitable cases was low, and the age group was not vital to our investigation, we were pleased to include all such nominated cases. This meant, in practice, that both degree of under achievement and specificity of under achievement varied somewhat in our case study samples.

Table 4.1 lists the children used in this initial study by school, by year group (or form), and indicates the methods used in their selection.

The Schools

Although we had circulated details of our project and our request for suitable mathematical underachievers to schools from several LEAs, our direct approaches had been to schools in one LEA in particular. Altogether eight large comprehensive schools were contacted, usually through Heads of Mathematics departments ; one declined to take part, and another was specifically contacted at a later stage (chapter IX). After an initial visit to outline our project and our requirements in terms of children and to answer queries, and a second visit when children were nominated or otherwise identified and our requirements

TABLE 4.1

THE SUBJECTS OF THE INITIAL STUDY

SCHOOL	SEX	YEAR	METHOD OF SELECTION
A	5M, 5F	1	JVR scores and school's own Mathematics test - regression.
A	1F	6	Discrepancy between Mathematics 'O' level score and other subjects at 'O' level.
B	1M, 2F	1	Poor Mathematics achievement relative to other subjects.
B	1F	2	JVR score and observed Mathematics achievement reports.
B	1M, 5F	6	Failure to pass 'O' level Mathematics and success in other subjects at 'O' level.
C	2F	6	Discrepancy between Mathematics 'O' level score and other subjects at 'O' level.
D	2M, 2F	1	Discrepancy between Mathematics set and English set.
E	1M	2	Discrepancy between Mathematics set and English set.
E	1M	5	Discrepancy between Mathematics set and English set.

in terms of testing sessions and time were considered, the first testing sessions were arranged.

The testing sessions themselves involved a member of the school staff, usually the Head of Mathematics, in locating the case-study children, arranging for the child to be absent from normal lessons (usually Mathematics) for the testing session, and finding a suitable location for the testing sessions. We are indebted to these teachers for the time and effort they expended on our behalf.

All the schools listed were large comprehensives, each catering for 1000 to 2000 pupils. The school's method of organisation varied from fairly formal banding or setting to a more informal mixed-ability structure. In the former, regular testing was common, with less formal continuous assessments the norm in the mixed classes. In between were schools in which pupils were "setted" for some subjects (usually including Mathematics), the set varying with the child's achievement in the subject concerned, as measured by various continuous assessments. Some schools used this system following one or two years of mixed-ability classes.

These differences between schools were not likely to be a factor in the developmental profiles of first-year pupils, some of whom had been in the schools for only one term when we saw them, but the differences did affect our study in the methods used for nominating suitable pupils and in the numbers found.

Administering the Tests

The tests were administered in the order described earlier in this chapter (p.171) as far as possible. This was true for all of the younger children, but for some of the sixth-formers the order tended to vary. This probably did not affect our results, since rapport with sixth-formers was usually established, before any testing began, in an informal interview in which we attempted to get some details of the child's underachievement, and any family history of mathematical difficulties.

Because of the reluctance of Heads of Mathematics to take children out of lessons other than Mathematics, the testing of children from one school was sometimes prolonged over several weeks. This was also partly due to the fact that, although as many as fourteen first year children from one school might be included in our sample, they could be scattered throughout six or eight different forms.

Generally we found that the children enjoyed our visits, both as a break from routine and as an excuse to skip mathematics lessons. They were often friendly and talkative, occasionally curious about what we were doing, and seemed keen to do their best in the activities and tests. There were one or two exceptions, two children in particular were extremely shy, and another tended to burst into tears rather easily complaining of severe headaches (her teachers confirmed that this was usual).

In the course of our work with these children we found two BAS tests which raised queries, either not covered by the manual or where we disagreed with the manual. The first occurred with the Block Design test when we were testing one of the sixth-form girls, S. When S was asked to construct a given design using nine blocks, she held two fingers of each hand over the design in order to see what each of the nine constituents should be. This seemed to us to be against the rules, but we could find nothing about the use of this strategy in the manual - and certainly she was the only child we have tested who thought of using such a method. The second occurred frequently with the younger (and usually less "cultured") children. One of the Similarities questions gives examples : sandal, slipper, boot ; the child has to supply another example and then say what they are examples of. Our children tended to supply correct examples such as dap, wellington, espadrille and then say they were examples of "shoes". We felt that either this should have been allowed as a colloquialism for footwear (after all, the examples are all bought from "shoe" shops) or "shoe" should have been one of the examples so that the child knew to look for a wider concept. Nevertheless, we scored according to the manual, for comparability with the norms given.

Test Results

These are arranged in order by school year group, and then by school within the year group, from first to sixth years.

The results given here, in Table 4.2, are raw scores for AH3 and percentile scores relative to the child's year group (as published

TABLE 4.2

SUMMARY OF TEST RESULTS OF INITIAL STUDY

SCHOOL	CHILD	AH3 V	AH3 N	AH3 P	AH3 TOTAL	LATERALITY	L - R	DIGIT SPAN FORWARD	DIGIT SPAN BACK	MATRICES	SIMILARITIES
A	a	18	11	20	49	R - R - L	**	96	4	65	65
	b	11	7	20	38	R - R - R	*	39	4+	65	65
	c	7	3	8	18	L - M - L	**	39	3	13	6
	d	10	5	15	30	R - R - L	*	39	3	65	35
	e	18	8	20	46	R - M - L		30	4-	65	97
	f	5	5	12	22	M - R - R	**	39	3+	4	15
	g	14	9	15	38	R - R - R	*	39	3	75	65
	h	12	5	18	35	M - L - L		30	3+	33	35
	i	15	10	13	38	R - M - R	*	60	4	75	35
	j	22	11	25	58	R - R - R		39	5+	44	65
D	a	13	6	18	37	R - R - R	*	8	3+	70	80
	b	27	13	24	64	R - R - R		60	4	94	35
	c	15	12	15	42	R - R - L	*	60	3+	65	80
	d	22	13	21	56	R - R - R		98	5	88	80
B	a	8	1	10	19	R - M - R	o	30	3	19	48
	b	11	8	20	39	R - R - L	o	98	6	50	48
	c	15	11	22	48	R - R - M	o	21	4	70	68
	d	20	11	18	49	R - R - M	o	97	5+	75	77
E	a	19	2	12	33	o	o	o	o	o	o
	b	23	23	31	77	o	o	o	o	o	o
C	a	26	21	24	71	R - R - R	o	82	5+	20	88
	b	30	25	28	83	R - M - R	o	97	5+	8	88
A	k	36	26	27	89	R - R - L	o	95	5+	25	99
B	e	21	23	22	66	R - R - R		50	4+	25	90
	f	16	22	24	62	R - R - L		34	5	20	68
	g	22	21	25	68	R - R - L		88	5	83	68
	h	10	16	15	41	R - R - R	*	43	4	20	99
	i	o	o	o	o	R - R - R	**	1	3	45	88
	j	o	o	o	o	R - R - L		1		o	o

in the appropriate test manuals) for Digit Span, Matrices and Similarities. Digit span backwards is recorded as the maximum number of digits which the child could usually report correctly, using the procedure specified in the manual for Digit Span, but requiring that the digits be reported in the reverse order. Laterality results are summarized for hand, foot and eye ; m indicates that different preferences were shown for different activities assessing the same organ preference. For knowledge of Left and Right, ** indicates definite difficulty and * indicates some difficulty. For all tests, O indicates not tested.

Discussion of Results

Two aspects of table 4.2 are in line with the results from the NCDS data analysis : that is, the prevalence of anomalous (non-R-R-R) laterality preferences, and the number of children experiencing some difficulty with Left and Right. The latter was hypothesized to be one of the factors underlying the poor copying designs scores of the SMU group, and was also the best predictor of learning difficulties in the Nichols and Chen [2] study. Non-right laterality preferences, especially left-handedness and cross-laterality of hand and eye, have long been associated with learning difficulties (e.g. Orton [8], Kinsbourne and Hiscock [9].

Another aspect of the results which struck us quite forcibly was the very large discrepancies shown by some of the children between different measures, especially Matrices, Similatiries and Digit Span tests, from the British Ability Scales. The test manual gives probabilities for discrepancies between pairs of tests, and many of our results have probabilities below .01, especially between Matrices and Similarities. These latter two tests are designed to test reasoning ability, but one tests Verbal reasoning and the other Non-verbal reasoning. Discrepancies between Verbal and Nonverbal abilities have been noted frequently in learning-disabled children (e.g. Kinsbourne and Warrington [10], Gosby [11], Benson and Geschwind [4].

Digit Span is one test of short term memory, and, while memory is not found to correlate very highly with general ability, discrepancies of the order found for some of our case study children are very exceptional.

On the basis of these results and their relation to the NCDS it seemed to us that there might be a need to investigate three areas in more depth : laterality, verbal-nonverbal differences, and memory. But first, we should try to obtain confirmation that any or all of these areas might be implicated in Mathematical underachievement in our case-study children. To this end four lines of enquiry were initiated. Firstly we tried to obtain more information about our laterality tests, their reliability in the form of test-retest agreement, inter-scorer reliability, and consistency over a longer period of time. Secondly, we obtained the co-operation of three of the sixth-form Mathematical underachievers in order to explore their ability patterns in greater depth. Thirdly, we investigated further two sixth-formers whose short-term memory scores had been exceptionally low. Finally, we obtained another sample of first-year comprehensive school children who were underachieving in Mathematics, in order to discover any bias in our initial sample, in terms of the areas discussed above, by comparison of the two samples.

These lines of investigation, together with their outcomes, are described in the next chapter.

APPENDIX 4.1

THE TESTS USED IN THE CASE STUDIES AND THEIR ADMINISTRATION

(i) AH3 : Short form. [6]

Publisher : NFER Publishing Company, Windsor.

Description : The test is divided into three sections, each consisting of 40 questions, using verbal, numerical and perceptual (i.e. diagrammatic or pictorial) materials respectively. In a balanced design, four types of reasoning are tested in each section (from : completion of series, odd-man-out / features in common, analogies, same/opposite, problems, basic relationships) in a multiple-choice format.

Scoring : Grades A to E are given on each section separately and also on total. A = top 10% B = next 20% C = middle 40%, D = next 20%, E = bottom 10%.
(For comparability with other tests we have converted actual scores to centiles based on these grades).

Reliabilities : Verbal .73 to .85, Numerical .82 to .86, Perceptual .66 to .83, Total score .88 to .94
(These depend on age group (9 to adult), same or parallel tests, split-half or test-retest design, and short or long time limits).

Validities : Correlations between : Verbal section and Verbal test NFER 15A 0.83, Verbal section and English Progress Test NFER D2 0.82 ; Numerical section and Middlesex Mathematics test 0.81 ; Numerical section and Mathematics attainment NFER DE2 0.82 ; All correlations with Total Score were higher than these (for 11-13 year olds)

Administration : As test Manual.

(ii) Laterality Tests

Publisher : Own version, not published

Description : Behavioural tests consisting of nine observations :

(1) child asked to write his name on a piece of paper.

(2) child asked to pick up and throw a paper ball as accurately as possible (usually into waste-paper bin)

(3) child asked to kick a paper ball as accurately as possible (to a corner of the room, for example)

(4) child asked to view examiner through hole in card while moving card from arm's length to close to his eye.

(5) child asked to listen to digital watch placed face down on a table, and to report any sound heard

(6) child asked to cut out a paper shape using scissors

(7) child asked to hop along a line on one foot

(8) child asked to count number of symmetries observed through a kaleidoscope

(9) child asked to listen to radio turned very low to identify the programme type.

In each case the equipment (pencil, paper, scissors etc.) was placed centrally in front of the child. The hand, foot, eye or ear used was recorded.

Reliability : No rigorous measures of reliability are available. However, two checks on reliability were made in the course of our case studies, both using very small samples. First, a small group of children were administered the laterality tests by two different examiners on the same day. Secondly, another small group of children were administered the laterality tests by the same examiner on two different occasions a year apart. These two investigations are reported in Chapter VI p. and Appendix 6.1, together with the results, showing that our results were moderately reliable.

Validity : These test items, apart from (5) and (9) which were not used in any of our calculations and discussions, clearly have face validity, and as ingredients of the Harris Tests of Lateral Dominance, they correlate well with that test.

Administration: The child was not told the purpose of the tests, but was asked to perform each act as accurately as possible. In each case the equipment was placed on a table, desk or floor, centrally in front of the child. In (1) and (6) the two pieces of equipment were placed one above the other ; in (6) the scissors had no handedness bias. In (4) the child was asked to hold the card with both hands throughout. In (5) and (9) the child was asked to listen without picking up the watch or radio (to eliminate bias due to the hand used to hold it).

(iii) Walking Backwards on a Line

Publisher : Own version, not published

Description : Behavioural test, consisting of one observation. The child was asked to walk backwards heel-to-toe along a straight line. Deviations from the line and any unsteadiness were recorded. This test was used in the NCDS in this form, and numbers of 11-year-olds who were 'steady', 'slightly unsteady' and 'very unsteady' are recorded in that data

Reliability and Validity : No reliability or validity studies were undertaken by us and none were reported in the NCDS literature. As one ingredient of the overall coordination assessment in the medical examination we should expect that it is known to be a reliable and valid measure.

This test was only used as an indicator of possible coordination difficulties, and is not central to our investigation.

Administration: The child was shown a straight line drawn on the floor and asked to walk backwards heel-to-toe along it as steadily and accurately as possible.

(iv) Test of Knowledge of Left and Right

Publisher : Own version, unpublished

Description : A behavioural test consisting of three observations :

1. child asked to point to his right eye
2. child asked to raise his left leg
3. child asked to touch his left ear with his right hand.

Scoring : Because knowledge of left and right on one's own body is usually fully developed long before secondary school age, and the three activities in this test do not involve more than this very basic knowledge (i.e. left and right on own body only - the child was not asked to mirror-image to someone facing him, or to identify e.g. a hand or foot in isolation or at an unusual angle), long hesitations or mistakes (even if corrected immediately) were scored for 'some difficulty' and if repeated on two or three of the activities as 'definite difficulty'.

Reliability and Validity : No specific studies were undertaken. The text has face validity and some confirmation was usually obtained by asking the child about difficulties with left and right.

(v) The Three BAS Tests : Matrices, Similarities, Digit Span

Publisher : NFER Publishing Company, Windsor

Descriptions : (a) Matrices

A booklet of designes, each of which has a missing part (1/4 or 1/9 of the whole) which the child is required to fill in "to complete the design using the part already done to find out how to do it". There is no time limit. The short version has a very steep difficulty gradient.

(b) Similarities

21 sets each of three words which have something in common. For each set, read out by the examiner, the child is required to give another example and then say what they have in common. There is no time limit. This test has a very steep difficulty gradient. Both example and common class must be correct,

(c) Digit Span

A series of digit strings of length two to eight digits, arranged in groups of five strings of the same length but graded difficulty. Each digit string, starting with the shortest and easiest is read aloud to the child at a uniform rate of two per second. The child is required to repeat the string back in the same order immediately after hearing it read out by the examiner.

Scoring : In each test, the child's score is the total number of items correct.

Reliabilities : Hoyt internal consistency coefficients for all scales, a test-retest/parallel for study, and scorer reliability studies on a number of scales are given in Manuals 1 and 2 to the BAS.

Administration: As Manual 3 to the BAS.

(vi) Backwards Digit Span

Publisher : Own version, not published

Description : As the BAS Digit Span test, except that for each digit-string spoken by the examiner the child is asked to repeat the digits of the string back in the opposite order (i.e. starting with the most recent).

Scoring : The average length of the longest strings correctly recalled was taken as the child's score.

Reliability and Validity : No specific studies were undertaken. Some evidence of likely reliability and validity from the BAS Digit Span test. This test was used only as an indication of possible ordering difficulties in STM, but is not central to our investigations.

Administration: Similar to that for BAS Digit Span test as in BAS Manual 3.

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CHAPTER V

AREAS OF FUNCTIONING RELATED TO UNDERACHIEVEMENT

Descriptions are presented of four lines of further enquiry designed to clarify ideas arising from the initial study, together with the results of these enquiries. Some confirmation of three areas of functioning apparently related to Mathematical underachievement is obtained.

In Chapter IV we identified three areas of functioning which, in our first sample, appeared to be prominent in mathematical underachievers. We therefore decided to look closer at these areas via our case studies to see if their apparent connection with mathematical underachievement could be sustained, with a view to a deeper investigation later if this proved to be the case. Such a finding would clearly be relevant to an investigation of dyscalculia, for if we could link deficits in such an area of functioning with neurological abnormalities and with mathematical under achievement, we should have a theoretical framework for the causality mechanism.

LATERALITY PREFERENCES

The first of the four lines of enquiry suggested to us by the results of our initial study concerned the laterality preferences of Mathematical underachievers. We saw in the last chapter that our initial sample of Mathematical underachievers contained a large proportion of children (63%) with non-right laterality preferences, (in fact, 33% of the children had crossed-laterality of hand and eye).

How reliable was this result? Although we had used the same, or similar, tests as those used in the NCDS, we were sampling a different population, both historically and in terms of age of children sampled. Was our sample typical of the population from which it was drawn? Was there an experimenter bias in testing the sample or experimenter error in individual measurements? Was the sample a-typical of such samples of mathematical underachievers?

In order to get some evidence on these questions we first tested the laterality preferences of a small sample of normal children from one of the schools supplying our study children. Two experimenters independently measured their laterality preferences on one occasion. Secondly the original study children from this same school were re-tested after one year. And thirdly a further sample of mathematical underachievers was obtained and their laterality preferences were measured using the same tests. [A further sample of 'normal' children was also tested at a later stage of our work (see chapter IX).] Results of these enquiries are presented in detail in Appendix 5.1 and table 5.2 respectively.

Although the samples are too small to expect significant differences, our results suggest that amongst normal children there are fewer non-right preferences, and in particular fewer cross-lateral cases. The fact that both normal and mathematical underachiever samples were tested by the same experimenter suggests that there was no systematic experimenter bias in laterality measurement, and this is also borne out by the close agreement between experimenters testing the same children. The latter finding, of consistency between experimenters, and the finding that similar measurements were obtained for some of the original sample when they were retested one year later, also suggests that the tests are reliable and laterality preferences are fairly stable. Indeed, all the laterality preference measures tend to support those found in the NCDS data, except that in our case-study children non-right preferences and cross-laterality of hand and eye are even more frequent than for the SMU group in the NCDS. That this finding was not merely a sampling error, but was an actual characteristic of the underachieving children, is supported by our second sample (discussed later in this chapter).

The suggestion, implicit in the above findings, that laterality may be connected in some way with mathematical underachievement, led us to propose an investigation of laterality via the literature and the NCDS data. This is described, and the results presented, in chapter VI.

Ability Profiles

For the second line of enquiry we obtained the cooperation of three of the sixth-form mathematical underachievers in completing individual case studies involving a good deal of individual testing and discussion. They gave up a considerable amount of free time in order to explore their ability patterns in greater depth, but did so willingly and apparently cheerfully. The three pupils were individually given short forms of the British Ability Scales battery suitable for their age group, the Embedded Figures test, a Mathematics test, and interviews on certain aspects of their background and discussion of their Mathematical performance. Some of the other sixth-formers from our sample also agreed to complete a Mathematics test and some also volunteered background information.

We first present brief descriptions, from personal observation and interviews, of the three sixth-formers studied in depth. As we shall see, they had several common features: all were girls (the sixth-formers in our sample tended to be volunteers, willing to give up a certain amount of free time, and concerned at their poor mathematical performance; although we were informed that there were some (fewer) boys underachieving in Mathematics, they seemed reluctant to participate for one reason or another. Only one sixth-form boy was included in our samples, and he limited his participation to two school periods - see next section); all were well above average in intelligence and were aiming at University places.

M ; M impressed us as a well-balanced, charming and articulate young woman, who seemed set to be a successful university student.

She was the youngest of three children. She reported that her mother had similar difficulties with Mathematics, although her father had none; her two elder brothers both had to repeat Mathematics at O-level, each passing at the second attempt.

Her problem with Mathematics was long-standing; she remembered extra coaching at junior school. When we saw her she was having private tuition in preparation for her fourth attempt at O-level Mathematics (which she required in order to go to University to read English).

She did not feel that her parents were over-anxious or that they pressurized her in any way. She reported that she did not like Mathematics because she could not do it, but that she did not hate the subject, and originally did not expect failure.

She reported her difficulty as inability to 'see' a way to solve a given problem. She had no difficulty with 'mechanical' arithmetic. We later confirmed that number facts and common algorithms were known, and that understanding the questions presented no difficulties.

S ; S appeared to be a well-balanced but quiet girl.

She was the only child of parents who both found Mathematics difficult; she reported that her mother had failed Mathematics at school, but was good at geometry.

Her problems with Mathematics appeared not to be very long-standing and had become noticeable early in secondary school, with the introduction of algebra in particular. She could not remember difficulties at junior school (but emphasis there may have been on 'mechanical' arithmetic), and was in the top set for two years at secondary school (general ability combined with more 'mechanical' type of Mathematics may explain this).

When we saw her, she had given up trying to get O-level Mathematics, and was studying A-level English, History and Art. All her O-level grades apart from Mathematics were C or above with A grades in English and History.

S also said that she did not like Mathematics since she started to find it difficult, but that she had not always disliked the subject. In particular, she said that Algebra frightened her - she did not panic when she encountered an Algebra question, but only when she had read the question and could not think what to do.

She reported her strengths and weaknesses in Mathematics, which we later confirmed, as knowing her number facts thoroughly, enjoying making graphs, constructing triangles, and so on; but as being unable to do Algebra, and having difficulty in finding ways to solve Mathematical problems.

<u>K</u> ; K seemed a well-balanced, articulate girl, perhaps a little immature.

She was the second of three children. Her mother had no difficulties with Mathematics, but she reported that her father was "totally illogical". Her elder sister had obtained a grade 'C' in O-level Mathematics, in line with some other subjects, and her younger brother, four years her junior, was "very good for his age".

Her difficulties with Mathematics were long-standing and had increased over time. She was having extra tuition for a second attempt at O-level Mathematics (her other O-level grades being five As and three Bs), which she required for entrance to University.

K said that she disliked Mathematics because she could not do it; she did not panic about it but was clearly frustrated and angry at her difficulties, since she saw herself (correctly) as a very able and intelligent student in general.

She reported that she knew her number facts thoroughly (later confirmed), but that she found most difficulty in finding appropriate methods for the solution of Mathematical problems.

These descriptions reveal both striking similarities and dissimilarities on first inspection, apart from those arising from their inclusion in this sample. This pattern was also found in the Test battery results, and in the specific mathematical difficulties that each experienced. As we shall see when these have been described, there do appear to be some common threads connecting these findings. First we present the results of the tests which we administered to each of these subjects.

Table 5.1 shows the results as percentile scores relative to age norms, or relative to some appropriate comparison group, where indicated. Raw scores are also included where these might be helpful. Figure 5.1 shows the British Ability Scales profiles of each of the three girls in graphical form.

One feature common to these results struck us very forcibly: the disparity between Verbal and Nonverbal reasoning as measured by the Similarities and Matrices subtests of the British Ability Scales*; in particular, the depressed scores on the Matrices test. These tests are representative of the types of reasoning referred to as 'Verbal' and 'Nonverbal' respectively. In our initial study, two other sixth-formers had V-NV discrepancies of this magnitude between centile scores on the matrices and Similarities subtests (but did not 'volunteer' for further work). Amongst the younger children, a few had quite large differences in the same direction and one had a large difference in the opposite direction. (See also Chapter VIII).

This second line of enquiry has therefore tended to sustain the case for a deeper investigation. That is, in view of the occurrence of Verbal-Nonverbal discrepancies in some learning-disabled

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*Footnote. The BAS manual gives some probabilities for discrepancies between scores on various subjects. Centile scores of 25 and 85 are equivalent to 'T'-scores of 43 and 60 respectively. For the age group 14-17 yrs. a 'T'-score discrepancy of 9 between Matrices and Similarities is significant .05. See pages 20-21 of this chapter.

TABLE 5.1

TEST RESULTS FOR THREE SIXTH-FORM GIRLS

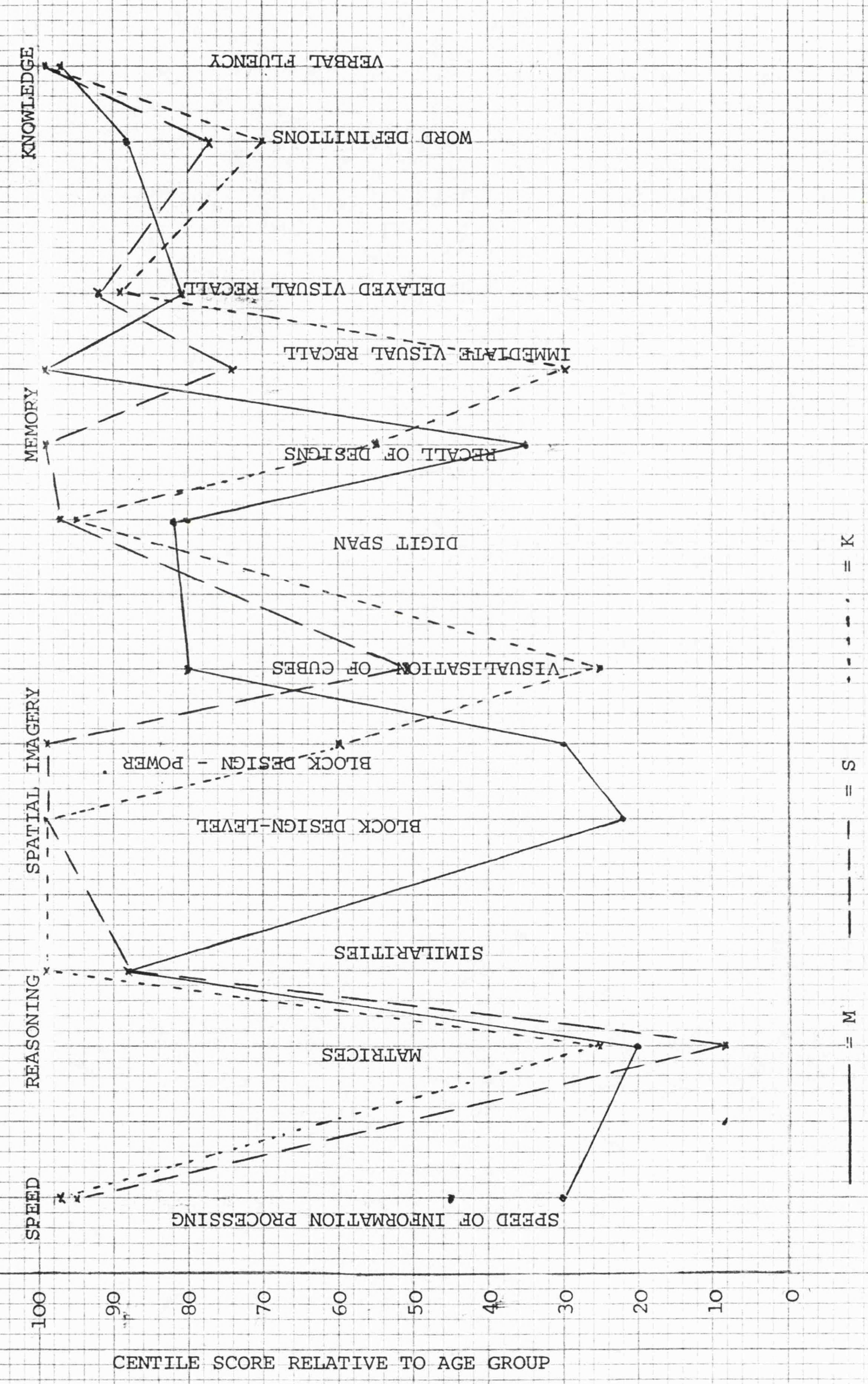
TEST	M	S	K
Laterality	R - R - R	R - M - R	R - R - L
AH3 - V	*30 (Univ. students) [26]	*50 (Univ. students) [30]	*70 (Univ. students) [36]
AH3 - N	10 (" ") [21]	20 (" ") [25]	30 (" ") [26]
AH3 - P	30 (" ") [24]	50 (" ") [29]	40 (" ") [27]
AH3 - Total	10 (" ") [71]	25 (" ") [84]	50 (" ") [89]
BAS - Speed of Info.Processing	30 (Peers) [4/10]	95 (Peers) [9/10]	97 (Peers) [9/10]
BAS - Similarities	88 (") [19/21]	88 (") [19/21]	99 (") [20/21]
BAS - Matrices	20 (") [8/11]	8 (") [7/11]	25 (") [8/11]
BAS - Digit Span	82 (") [30]	97 (") [33]	95 (") [32]
Digit Span Backwards	[5]	[5]	[5]
BAS - Recall of designs	35 (Peers)	99 (Peers)	55 (Peers)
BAS - Immediate visual recall	99 (") [19/19]	74 (")	30 (")
BAS - Delayed visual recall	81 (") [15/19]	92 (")	89 (")
BAS - Block design-level	22 (") [14/16]	99 (") (16/16]	99 (") [16/16]
BAS - " " -power	33 (") [10/16]	99 (") [16/16]	60 (") [11/16]
BAS - Visualisation of cubes	80 (") [15/18]	51 (")	25 (")
BAS - Word definitions	88 (") [33/37]	77 (")	70 (")
BAS - Verbal fluency	97 (")	99 (")	99 (")
Embedded figures	Field Indep.	Field Indep.	Field Indep.

* Scores are percentiles relative to comparison group

( ) = comparison group

[ ] = raw score on test

FIGURE 5.1 : BRITISH ABILITY SCALE PROFILES OF 3 SIXTH-FORM MATHEMATICAL UNDERACHIEVERS



children quoted in the literature (see Chapter I), especially large differences in favour of Verbal ability in the Gerstmann syndrome, these findings suggested that we should examine such differences further. We therefore decided to look at V-NV differences in the NCDS data, although the 'Verbal' and 'Nonverbal' tests used there were not directly comparable with Similarities and Matrices. This investigation is described in Chapter VIII.

We also decided to look at the difficulties in doing mathematics experienced by children with large V-NV differences in order to look for commonalities (if any), for differences between these children and other mathematical underachievers, and for directional difference characteristics (if any). This latter investigation also tied in with our findings in connection with two other sixth-form mathematical underachievers, to be described in the next section. Moreover, we have already discussed the need for a further sample of under-achievers in order to check the consistencies of percentages of non-right and cross-lateral preferences between such samples. This further sample, therefore, will also be used to investigate the consistency of the occurrence of large V-NV differences in different samples, and to look at differences in mathematical difficulties between children in the sample. The choosing of this second sample, the tests administered, and the results, are presented later in this chapter.

TWO SIXTH-FORM UNDERACHIEVERS WITH POOR DIGIT SPAN SCORES

Our third line of enquiry concerned another discrepancy between sub-scale scores. We have already mentioned that discrepancies between Similarities and Matrices were not the only remarkable discrepancies found in the sixth-form sample. Two of the sixth-formers appeared to have large discrepancies between Digit Span scores and other ability measures. Although Digit Span has one of the lowest sub-scale correlations with total ability on the WISC, and although restriction of range would reduce any correlation, the degree here is worth noting, for in samples of children of similar ability Digit Span has little correlation at all with ability, although between groups of very different ability it does become a very powerful discriminator [1]. It is therefore very curious to find children preparing for 'A'-levels (with 'O'-levels to their credit) whose Digit Span scores put them in the bottom 10% of their age group. We now report on two such cases.

One of these, a boy, J, had given up Mathematics after failing 'O'level, although he had some good results in non-science subjects and was currently studying A-level languages. He told us that his mother had great difficulties with Mathematics, although his father and brother had none. His difficulties were long-standing and went back through junior school. Perhaps he felt his failure more acutely because his (younger) brother was specializing in Mathematics.

Because of time limitations, we administered only two sets of tests from our test battery: the laterality tests, (J was found to be cross-lateral, preferring his right hand and left eye); and the digit span tests, where his performance was so poor and variable that we were struck by it and decided to investigate it further in the time available. J was therefore asked to "think aloud"* while attempting a Mathematical test (NFER Basic Mathematics Test F-G), which he should have found easy. This yielded a series of mistakes (see Chapter VII for more details) consistent with short-term memory failures. Reasoning that if a poor short-term memory was the cause of J's poor Mathematical performance, then his brother would not have a poor short-term memory, in fact, might be expected to have a superior Digit Span score, we tested this prediction. In fact we found that J's brother's Digit Span score was in the superior range and, moreover, was reliable from item to item.

The second sixth-former, a girl, V, whose Digit Span performance was even worse than J's, also reported that other members of her family had difficulties with Mathematics. Her own difficulties had become apparent and grown worse at secondary school. On the Digit Span measure she could repeat back only four digits without error, putting her in the bottom 1% of her age group. A girl with six 'O'-levels to her credit should clearly have been higher than this on the Digit Span scale (as is shown by the probability table for sub-scale score differences in the BAS manual).

*This method will be described in detail and discussed later in this chapter.

A further investigation of this case, in which we asked V to "think aloud" while attempting a Mathematical test (NFER Basic Mathematics Test F-G), again produced unsystematic errors consistent with short-term memory failures.

These two sixth-formers, although exhibiting poor performance in this short-term memory task, seemed to have less difficulty with long-term memory. Each had good grades in factual 'O'-level subjects such as history, biology and languages. Moreoever, they did seem able to recall Mathematical facts, such as tables and algorithms, in isolation (when there was no additional load on memory).

The findings that errors on the Mathematics test could be explained in terms of short-term memory failures, that such errors were unsystematic, and that strategies, concepts and understanding of questions appeared to give little difficulty, all suggest that short-term memory played a prominent role in mathematical under-achievement in the two cases studies.

We therefore decided that Short-term Memory should also be investigated in more depth, and this is done in Chapter VII.

THE SECOND SAMPLE OF MATHEMATICAL UNDERACHIEVERS

The remaining line of enquiry, to be pursued in local case studies, was to select a different sample of mathematical under-achievers, with several objectives in mind. One objective was to increase the overall size of our group of underachievers. Another was to test for the occurrence of non-right and crossed laterality preferences in similar proportions to those of our first sample, to test for the occurrence of large V-NV differences, and to test for the occurrence of poor Digit Span scores. Similar findings to those described above would give support to the view that laterality variables, large V-NV differences, and poor memory measures are related to mathematical underachievement. In the introductory chapter (Chapter I) we briefly touched on the neurological significances of each of these three areas of functioning, and these chains of influence from neurological functioning to mathematical underachievement are explored further in Chapters VI to VIII.

A final objective in choosing our second sample of mathematical underachievers would be to attempt to link the various 'significant' areas of functioning (laterality, V-NV differences, short-term memory) with different types of mathematical difficulty. Should this prove possible, it would give us some indication of the relative independence of the 'significant' areas. Should such links also prove explicable in neurological terms, it would also give us more indirect evidence supporting the existence of dyscalculia.

In order to compare this second sample with our previous one, it was necessary to use the same basic test battery. In addition, we needed to find some procedure which in a reasonably short space of time would diagnose the mathematical difficulties that this underachieving group were experiencing.

THE PROCEDURE FOR DIAGNOSING MATHEMATICAL DIFFICULTIES

Our requirements for this procedure were:-

(i) That it should sample a wide range of mathematical activities.

(ii) It should assess difficulties with "mechanical" arithmetic, mathematical problem solving, and mathematical concepts.

(iii) It should be administered by us (to give uniformity of assessment between schools and classes).

(iv) It should be capable of yielding worthwhile information in ½ to 1 hour per child.

(v) If possible, it should indicate both pupils strengths and weaknesses.

A survey of the literature revealed several potential methods, falling into roughly two groups. The first of these was examination of the pupils' schoolwork or pupils' written answers on some Mathematics test or diagnostic Mathematics test. The troubles with these methods are that they tend to indicate in which questions errors occurred, but give no indication, in most cases, of the source of error, and, in the case of diagnostic tests, they sample a very narrow range of mathematical activity (usually mechanical arithmetic). The second group of methods of diagnosis usually starts with one of these sources of written errors and then goes on to an examination of the source of error by questioning the child as to how he arrived at the erroneous result. (e.g. Bailey [2], Kent [3], Clements [4]). The troubles with this type of method are: the time taken (for example, Clements estimated that to cover the errors on a 40-question Mathematics test averaged over 2 hours per child), the unforthcomingness of some children when questioned on their methods, even with people they knew quite well (e.g. Kent [3]; we would have seen our sample on only two previous occasions), and the omission of erroneous methods which led to correct answers (e.g.* To find the area of a triangle with sides 5, 12 and 13 units a child might add the three integers together; his answer of 30 would be accepted and not explored further).

We decided to explore all these methods and to improvise our own in the light of that experience to get closer to fulfilling our objectives. An examination of the childrens' exercise books showed that most current exercise books covered too few topics, consisted almost entirely of practice on a single theme (and hence did not test strategy choice, memory for problem types etc.), and contained very little information on how well mathematical concepts were understood and remembered. (However, we did come across some well-known errors in this way - children who multiplied from left to right, others who confused + and X signs).

An examination of the answers to a written Mathematics test,

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*This is an actual case which came to our notice.

which did cover a wide range of topics, was also not very informative about the sources of error; moreover errors were only recorded when they led to the wrong answers. Occasionally it was possible to guess, from the wrong answer, how the error had arisen, but this was clearly speculative.

We also tried Clements' method [4] using a set of mathematical problems, except that the children were simply asked to solve the problems for us and questioned on each stage of their solutions, without first having attempted written answers. That is, we did not choose problems on which the child had previously made an error. We found that we spent far too long on each question to cover an adequate range of topics; indeed, some children were reluctant to reply to our questions (as were some of the children in the literature) and some seemed to interpret any question on method as implying that they had made a mistake, which they then tried to correct! We formed the impression that this method would be more effective if administered by a well-known figure such as the child's regular teacher; and that our difficulty was that we had had only two previous contacts (in general) with the child. Moreover, it ideally needed more time; we found that we had to be constantly urging quick replies to questions or forfeit valuable time waiting for a child to respond at leisure.

In the end, we found that the method which gave the most information in the time available was to ask the child to solve each problem aloud, beginning by reading the question and then "thinking aloud" right through to the answer. We interrupted as little as possible, but occasionally asked questions when the child appeared to be in difficulties. This method worked well with most children; only two found it almost impossible to think aloud and refused to answer questions (they would probably have had similar difficulties with Clements' method). We gave the children every encouragement to talk and accepted all their solutions, whether correct or not, without comment. Help was given when requested. The actual test score was never recorded: it was the nature of mistakes and difficulties, the methods used, and the degree of difficulty manifest in each operation in which our interest lay.

Again by trial and error, we found that the 'best' method of recording the pupil's performance was to write down verbatim his utterances while solving each problem. We had considered video-recordings and tape-recordings, but the latter seemed to inhibit the children (in a one-to-one situation) so much that most valuable information was lost, whereas they hardly seemed aware of our own scribblings! Even the sixth-formers were affected by the appearance of a tape-recorder, and one of them explained that it made her feel self-conscious, and when trying to "think aloud" she "just dried up".

The actual Mathematics test used, depended on the age of the child and his ability. The ones most often employed were NFER's Basic Mathematics Tests D-E and F-G, which cover a wide range of topics and give scope for the assessment of 'mechanical' arithmetic, mathematical concepts, and strategies.

For the obvious reason that we wanted the children to be as familiar with us and as relaxed as possible when doing this diagnostic activity, it was always the last test administered. About one hour was spent with each child working on this 'diagnostic' activity, irrespective of the number of questions attempted in that time.

THE SAMPLE

For this part of our investigation, two large comprehensive schools agreed to participate. Each had its own basic Mathematics test which was administered to all first-year pupils, and a list of JVR-scores from the children's Junior schools.

A regression of Mathematics test scores on JVR-scores was used to pick out children who were clearly underachieving in Mathematics on the basis of these scores.

TEST RESULTS

Table 5.2 presents a summary of the results of this second sample of mathematical underachievers in local schools. Symbols in this table have the same meanings as those in table 4.2; AH3 scores are raw scores which give an indication of relative degrees of difficulty with verbal, numerical and perceptual materials; Digit Span, Matrices and Similarities scores are percentiles relative to the child's age group; backward Digit Span is the number of digits the child could remember and repeat in the reverse order; while for Left-Right discrimination and 'Walking backwards on a line",

TABLE 5.2

SUMMARY OF TEST RESULTS OF SECOND SAMPLE OF MATHEMATICS UNDERACHIEVERS

SCHOOL	CHILD	AH3 V - N - P	AH3 TOTAL	LATERALITY H - F - E	L - R	WALKING BACKWARDS	DIGIT SPAN FORWARDS	DIGIT SPAN BACK	MATRICES	SIMILARITIES
A	l	17 - 7 - 15	39	R - M - L			29	4	16	96
	m	15 - 3 - 18	36	R - M - L	**	*	10	3	16	65
	n	16 - 9 - 15	40	R - R - R	**		23	4	61	47
	o	18 - 10 - 17	45	R - R - L	*		49	3	34	88
	p	17 - 4 - 16	37	R - R - M			68	4½	34	78
	q	14 - 5 - 15	34	R - R - R	**		23	5	83	80
	r	9 - 4 - 17	30	R - R - L	**		11	3	17	35
	s	10 - 4 - 13	27	R - R - L	**	*	29	4+	60	78
	t	14 - 11 - 21	46	R - R - R			49	4	82	78
	u	6 - 9 - 18	33	R - M - L	*		59	5+	60	65
	v	11 - 6 - 4	21	M - M - R	*		3	3	4	46
	w	11 - 5 - 23	39	R - R - L		**	10	3+	34	88
	x	8 - 8 - 17	33	L - M - R	*		15	4	16	78
	y	1 - 5 - 8	14	R - R - R	**		40	4	17	22
F	a	12 - 6 - 17	35	R - M - R			18	5	32	86
	b	14 - 6 - 16	36	R - M - R			75	3+	33	41
	c	12 - 7 - 14	33	R - R - R			73	3	15	63
	d	14 - 4 - 18	36	R - R - R			33	4	14	17
	e	11 - 4 - 16	31	R - R - L		**	68	4½	32	17
	f	7 - 4 - 22	33	R - R - R		*	33	4	58	10
	g	9 - 6 - 12	27	R - L - L	**		68	3½	58	41
	h	16 - 17 - 22	55	R - R - R			86	3½+	58	99
	i	12 - 8 - 20	40	R - R - L			6	3½+	58	26
	j	12 - 15 - 17	44	R - M - R	**		18	2½+	58	26
	k	8 - 10 - 16	34	R - R - L			53	5+	80	7
	l	16 - 6 - 22	44	R - R - L			4	3½	32	63
	m	10 - 3 - 22	35	R - R - L	*		68	4	15	63
	n	13 - 6 - 18	37	R - R - M	**		73	3+	32	63

*indicates some difficulty or unsteadiness, **indicates definite difficulty or unsteadiness.

DISCUSSION OF RESULTS

Comparison of tables 5.2 and 4.2 supports the hypothesis that the two samples of underachievers are similar to one another in the unusual incidence of non-right and crossed-laterality preferences, the unusual incidence of large V-NV discrepancies, and the unusual incidence of poor Digit Span scores in children of average or above average ability.

Comparison of either underachieving sample with a sample of 'normal' children on laterality preferences, suggests that non-right and crossed laterality preferences may be more common in Mathematical underachievers. However, our samples are too small for the pattern to reach statistical significance.

Comparison of Digit Span, Matrices and Similarities scores with distribution of score differences given in the manual, suggests that both the incidence of large V-NV differences (Matrices and Similarities) and of low Digit Span scores (Digit Span and Similarities) are statistically significant in these samples of underachievers.

How independent are these 'significant' areas of functioning? (i.e. laterality, V-NV differences, poor Digit Span). Our two samples seem to give different answers to this question. We now explore this question, and the significance of each area by considering each in turn, preliminary to our investigations in depth in Chapters VI to VIII.

MEMORY FEATURES

In the initial sample three children (out of 29) had Digit Span scores at or below the 15th. centile for their age. Of these, one had no non-right laterality preferences and compatible V-NV scores much higher than Digit Span; one was cross-lateral but not tested for V-NV differences; and the third had no non-right laterality preferences but quite a large V-NV difference, with higher Verbal score.

In the second sample, five children in school A (m,r,v,w,x) had digit span scores at or below the 15th. centile; these were all accompanied by low scores on Matrices ($\leq$ 34th centile), but not on Similarities (35th to 88th centiles) and all exhibited some degree of cross-laterality (one was mixed-handed and right eyed). AH3 scores indicate that abilities were in the centile range 10 to 50, although JVR-scores ranged from 92 to 109.

The difference in assessment of ability between AH3 and JVR is usually due to depressed scores on AH3-N relative to AH3-V and AH3-P, because of difficulties with numerical material. The lowest AH3 score (subject Av) and low memory score are compatible, but the other four AH3 scores (33rd to 47th centiles) suggest that memory scores are out of line.

Two children in school F (i,l) also had very low memory scores (4th and 6th centiles), each had discrepant Matrices-Similarities scores (in opposite directions) and both were cross-lateral. AH3 scores for these children indicated that abilities were in the range 50 to 60th centiles, with JVR-scores of 102 and 100; these scores would be expected to accompany higher Digit-Span scores.

For all seven of these children from the second sample backward-span scores were 1 to 2 digits below forward-span length, as is usual, but meant in practice that three of these children could not hold in memory and reverse more than three digits.

Although all seven of these low Digit-Span children had discrepant scores on Similarities and Matrices (5 of them having one above-average score), only one of them qualified for our V-NV-discrepancy group (see below).

Eight other children from the second sample may be mentioned in connection with memory scores. Subjects A_o,F_b,F_c,F_h,F_n had forward spans of 5½,6,6,6½ and 6 digits but backward spans of only 3,3,3,3½ and 3 respectively and subject F_j, with a forward span of 5 digits (18th centile) could only reverse 3 digits if one of them was repeated (e.g. 922 or 447). This may indicate difficulties with temporal ordering for these children. On the other hand, subjects A_q,F_a and F_k had backward spans similar to forward spans, the latter being rather low in two cases; and two of these children (F_a,F_k) are included in our V-NV discrepancy group.

LATERALITY FACTORS

In our first sample, 10 out of 29 children were right-homolateral while 9 were cross-lateral and a further 4 were somewhat cross-lateral (mixed-handed or mixed eyed).

In our second sample, 14 out of 28 children were cross-lateral while only 8 were right-homolateral.

These figures are quite striking when compared with the NCDS data (27.7% cross-lateral; 58.2% right-homolateral at age 11) and with those of our "normal" class (in Chapter IX), where less than 20% were cross-lateral and just under 60% were right-homolateral.

The connection between laterality and low Digit-Span in this second sample has already been remarked; the 7 children with very low Digit-Span scores were all somewhat cross-lateral (one mixed handed and right eyed); but only 1 of 3 was cross-lateral in the first sample.

There also seemed to be a connection between laterality and large V-NV differences in our second sample. Of the 12 children whose Matrices and Similarities scores differed by more than 40 centiles, 8 were somewhat cross-lateral (one was right handed and mixed eyed); while of the 6 children whose Matrices and Similarities scores differed by more than 50 centiles, 5 were cross-lateral. But in our original sample, of the 2 younger children whose V-NV difference was 40 centiles or more, neither was cross-lateral; of the 7 sixth-formers whose Matrices and Similarities scores differed by 40 centiles or more, 2 were cross-lateral.

V-NV DISCREPANCY FACTORS

In the second sample 12 out of 28 children had discrepancies of 40 centiles or more between Matrices and Similarities test scores. Of these, 6 differed by more than 50 centiles, and 3 by more than 60 centiles. In our initial sample the figures showed that 2 out of 18 younger children had at least 40 centile discrepancies, one of these being 59 centiles; while 7 out of 8 sixth-formers had centile discrepancies greater than 40, three of these discrepancies being greater than 70 centiles.

In the initial study the difference in one of the two younger children was in favour of Matrices, while the 7 sixth-formers all had higher Similarities scores.

In the second study 10 differences were in favour of Similarities and 2 in favour of Matrices. In general, these differences tended to be confirmed by AH3 partial scores; for the "verbal" children, raw scores on AH3-V were higher (1 exception) than AH3-N (and often higher than AH3-P), while for the "nonverbal" children AH3-V was considerably lower than AH3-P and in the more extreme case also lower than AH3-N.

According to the BAS manual, a discrepancy of 8 'T' scale points [equivalent to 6 centile points at the extremes, i.e. 1st to 7th centiles or 93rd to 99th, rising to 34 centiles at the middle of the range, i.e. 33 to 67th centiles] is significant P = .05. We question this statistic on the basis of our experience with a "normal" class (see Chapter IX), where 12 out of 26 children had 'T'-score differences of more than 8. We used the shorter forms of some of the tests, where a difference of one mark can change centile position by 10; and this may account for our disagreement with the BAS manual. We have therefore decided to concentrate only on 'T'-score differences of 16 as being significant (only the two confirmed Mathematical underachievers in the "normal" class had such large differences - see Chapter IX), for the purpose of estimating the prevalence of abnormal score differences in our samples. This convention means that in our second sample, seven out of 28 children (Al,Ao,Aw,Ax,Fa,Fh,Fk) had significant score differences. In addition, subject Ff, with a 'T'-score difference of 15 in favour of Matrices, may also be considered to have an abnormal difference, because in our "normal" class no child had a 'T'-score differerence greater than 5 in favour of Matrices.

THE 'DIAGNOSTIC' MATHEMATICS TESTS

These tests were used to diagnose each child's own strengths and weaknesses in Mathematics. The information gained from these tests was used in three ways.

(i) The child's performance was related to other test results. For example, a child writing fifty-one as 15 might also have been observed to have a very poor backward-Digit Span; both of these are compatible with a temporal order difficulty. Or, a child unable to draw mirror images may also have been observed to have difficulty with Left and Right. These strongly suggest some form of spatial deficit.

(ii) Commonalities were sought between areas of difficulty (error types etc.) and other test battery results. Although this yielded no clear-cut results, we were left with some impressions. Children with very poor Digit Span scores tended to make erratic computation errors. Children with large V-NV differences in favour of Verbal abilities tended to have difficulty in finding the correct method or strategy for solving problems. They read the question correctly, and could say what the question asked them to do, but then the child would say "I don't know how to start" or "I haven't done one like this before" or "I don't understand" (the meaning of the latter, on questioning, being "I don't understand <u>how</u> to do it"). On the other hand, those children with large V-NV differences in favour of non-verbal abilities tended to have difficulty in understanding what the questions were asking. Again, the questions were usually read correctly, but then the child might say "What does that mean?" or "I don't understand". Simply re-wording the question was sometimes enough to enable the child to reach a correct solution. As with some "poor Digit-Span" types, these "Nonverbal" children did seem to have strategies for solving problems once they had understood the question.

(iii) The strengths and weaknesses of the child's mathematical performance, as revealed by our diagnostic procedure, were reported to the school.

This 'diagnostic' procedure has proved capable of yielding useful results; we feel it has great potential value to any investigation of remediation of underachieving children. We should also like to see it used to compare the errors and difficulties of underachievers with those of achievers of similar general ability.

AGE AND UNDERACHIEVEMENT

We have shown that for two separate samples of mathematically underachieving children, underachievement does appear to be connected with three areas of functioning: short-term memory, laterality preferences, and large Verbal-Nonverbal differences. On the basis of these two samples, there may, or may not, be connections between these areas.

We noticed that, in general, the older the child (i.e. sixth-formers vs first-formers), the more pronounced the underachievement and the significant area of functioning. This is to be expected: the hierarchical nature of Mathematics and the tendency to 'give up' on a subject with which he has unusual difficulty combine to make it more difficult for a child to catch up once he does drop behind, and make it more likely that he will fall further behind. This raises the question of how early lasting difficulties can be diagnosed, and what form they take.

We therefore approached several local junior schools, since we felt it would be worthwhile to consider whether children with early Mathematics difficulties exhibit any of the factors hypothesized from our two samples. The schools approached were able to suggest some underachieving pupils in general and low attaining pupils in Mathematics, but when looked at more closely they rarely revealed underachievers whose difficulties were specific to Mathematics, and whose overall ability was at least average. Acknowledging the difficulties in identifying such pupils, this area of investigation was not developed in the study, though we do include studies of two younger children. One came from the approach to junior schools, and the other, nearer the end of our investigation, from the parents of a young girl who approached us directly.

The latter case is discussed in Chapter VII, since this girl appeared to have a short-term memory deficit. Not only was her Digit Span score low, but her parents reported that she showed great reluctance to carry messages, or run errands, in case she forgot what she was supposed to say, or ask for. Her mathematical errors were erratic; she would get a question correct on one day and make an error on the same question the following day. However, poor memory was not diagnosed on Digit Span score alone; without these added facts we might have accepted Digit Span as low but not significantly so. That is, at age 9, the diagnosis was much less reliable than for our two sixth-formers.

The other younger child, again aged 9, was also doing quite well in junior school except for Mathematics. Although her test results, Matrices and Similarities, did not reflect it, we gained the impression as she attempted our battery of tests, of a very 'Verbal' child. She had a good memory, and quite a good grasp of Mathematical facts and tables. However, one reason for her poor Mathematical performance became apparent when we presented her with easy problems in which she had to identify the Mathematical operation required for solution. (e.g. Mary had 8 sweets. She gave three to John. How many had she left?). Her replies of "Add", "Take Away", "Times" and "Share" to such questions appeared to be random guesses. That is, like older 'Verbal' children, she seemed to have difficulty in identifying the strategy or method to solve problems. The school identified this child for us immediately when we explained our requirements. They could offer no simple explanation (such as frequent moves, long absences, emotional/behavioural problems etc.). The fact that her difficulty was known to the teachers suggests that teaching methods and curriculum (e.g. very formal teaching, rote learning of facts and algorithms without understanding, or concentration on 'mechanical' arithmetic) cannot fully explain this case, although it must be borne in mind as a possibility. [The reason the V-NV difference was not pronounced, may be due to the nature of the tests used. An inspection of the Matrices test, in particular, suggests that different approaches may be used for the early examples, which are the only ones expected to be solved correctly at age 9].

There is a suggestion here, therefore, that the factors hypothesized as relating to Mathematical underachievement in older children may also be identifiable in younger children who may be underachieving in Mathematics. This aspect clearly needs more research, especially as early identification is desirable in cases of underachievement. However, these two examples also show that we may need more sophisticated or detailed tests for younger children.

We now go on to look in more detail at the three areas of functioning which, as indicated, appear to be connected with mathematical underachievement.

APPENDIX 5.1.

MEASUREMENT OF LATERALITIES - CONSISTENCY BETWEEN EXAMINERS

Table 5.1.1 shows the consistency between two different examiners testing the same 9 children on the same day.

TABLE 5.1.1 CONSISTENCY BETWEEN EXAMINERS

Child	Examiner	H	H	F	E	*Ea	H	E	F	*Ea	H-F-E
1	1	R	R	R	R	L	R	R	R	R	R-R-R
	2	R	R	R	R		R	R	R		R-R-R
2	1	R	R	R	L	L	R	R	R	R	R-R-M
	2	R	R	R	R		R	R	L		R-M-R
3	1	R	R	R	L	R	R	R	R	R	R-R-M
	2	R	R	R	L		R	R	R		R-R-M
4	1	R	R	R	R	R	R	R	R	R	R-R-R
	2	R	R	R	R		R	R	R		R-R-R
5	1	R	R	R	R	R	R	R	R	R	R-R-R
	2	R	R	R	R		R	R	R		R-R-R
6	1	R	R	R	R	R	R	R	L	R	R-M-R
	2	R	R	R	R		R	R	L		R-M-R
7	1	R	R	R	L	L	R	R	L	R	R-M-M
	2	R	R	R	R		R	R	R		R-R-R
8	1	R	R	R	R	L	R	R	R	R	R-R-R
	2	R	R	R	R		R	R	R		R-R-R
9	1	R	R	R	R	R	R	L	R	R	R-R-M
	2	R	R	L	R		R	R	R		R-M-R

*Omitted from all calcualtions and discussions.

Total number of children with cross-laterality H X E
Examiner 1 0 Examiner 2 0
Total number of children with non-right preferences
Examiner 1 5 (55.6%) Examiner 2 4 (44.4%).
57 out of 63 measurements were the same for both examiners.
Prevalences of cross-laterality and non-right laterality were respectively lower and similar to the NCDS population at age 11.

MEASUREMENT OF LATERALITIES - CONSISTENCY OF MEASURES OVER 1 YEAR.

Table 5.1.2 shows the consistencies of laterality measurements on the same 8 children retested after 1 year.

TABLE 5.1.2 CONSISTENCY OF LATERALITY PREFERENCES OVER 1 YEAR

Child	Test-Retest	H	H	F	E	*Ea	H	F	E	*Ea	H-F-E
1	T	L	R	L	L	L	R	L	L	L	M-L-L
	R-T	L	L	L	L		L	L	L		L-L-L
2	T	R	R	R	L	R	R	L	L	L	R-M-L
	R-T	R	R	L	L		R	L	L		R-L-L
3	T	R	R	R	L	R	R	R	L	R	R-R-L
	R-T	R	R	R	L		R	R	L		R-R-L
4	T	R	R	R	L	L	R	R	L	R	R-R-L
	R-T	R	R	R	L		R	R	L		R-R-L
5	T	R	R	R	R	R	R	R	R	R	R-R-R
	R-T	R	R	R	R		R	R	R		R-R-R
6	T	R	R	L	R	L	R	R	R	R	R-M-R
	R-T	R	L	L	R		R	R	R		M-M-R
7	T	R	R	R	R	L	R	R	R	R	R-R-R
	R-T	R	R	R	R		R	R	R		R-R-R
8	T	R	R	R	R	L	L	R	R	R	M-R-R
	R-T	R	R	R	R		L	R	R		M-R-R

*Omitted from all calculations and discussions.

Total number of children with cross-laterality H X E
At Test 3 (37.5%) At Retest 3 (37.5%)
Total number of children with non-right preferences (H,F,E)
At Test 6 (75%) At Retest 6 (75%)
52 out of 56 measurements were the same on both occasions.
Prevalences of cross-laterality and non-right laterality were both higher than those of the NCDS population at age 11.

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CHAPTER VI

LATERALITY PREFERENCES

Different measures of laterality are discussed, and laterality preferences as used in this thesis are defined. A review of the literature on connections between laterality and cerebral organisation, laterality and achievement and theories of the origins of laterality preferences follows. Laterality prevalences at ages 7 and 11 are presented for children in the NCDS, and the stability of such preferences over the period 7 to 11 years are considered and discussed. These preferences and changes in preferences are also discussed in relation to children's ability and attainment measures. Finally, laterality preferences of various subgroups, defined by 'educational' or 'clinical' criteria are compared with those of the total NCDS population.

In Chapter III we saw that the group of children (SMUs) from the National Child Development Study who were underachieving by more than two standard errors in Mathematics but whose Reading Comprehension scores were not more than one standard error below expectation (based on regressions on Ability scores), contained a subgroup characterised by extreme discrepancies between achievements in Mathematics and Reading Comprehension at age 11 (i.e. Mathematics at least three standard errors below expectation or Reading Comprehension two standard errors above expectation). This subgroup tended to have high levels of abnormal births, abnormal pregnancies, or head injuries; abnormal levels of poor co-ordination of various kinds; extreme scores on physical measurements; and 'deviant' (non-right) laterality patterns. Our case studies of children in local schools also produced high levels of 'deviant' laterality patterns. We therefore present a study of this variable, 'deviant' laterality, and its relation to achievement and underachievement, in the belief that it may characterise one form of Mathematical underachievement.

After a consideration of laterality from a theoretical perspective, we shall present an empirical study of laterality preferences in the NCDS data, their prevalences at 7 and 11 years, their stability over time, and their relationships to ability and achievement measures. We shall also consider 'deviant' laterality preferences in certain 'educationally' and 'clinically' defined subgroups selected from the NCDS data, and in our two samples of Mathematical underachievers from local schools. As a preliminary, however, it is important to explain the terminology we have used in this chapter.

TERMINOLOGY

The term 'laterality' has been used in the literature to refer to asymmetries in brain function and cerebral organisation, as well as to the performance on a number of different behavioural measures. The latter have included simple hand, foot, and eye preferences on one or more tasks, a combination of such preferences, strength of such preferences, as well as ear asymmetries in dichotic listening tasks, visual asymmetries in tachistoscopic viewing tasks, EEG asymmetries, and evoked-potential asymmetrices. (See for example Kinsbourne and Hiscock [1]).

We shall limit the use of the term 'laterality' to refer to hand, foot or eye preferences on a number of behavioural measures (described in the text). In so doing, however, there is an underlying inference, to be discussed later, that a child's cerebral functioning may be related to the behavioral measures in such a way that it would interact differentially with the processing of other information.

We shall use 'mixed laterality' to refer to preferences of a single organ (hand, foot or eye) that vary with the task, and to ambidexterity (equal preferences for right and left). 'Inconsistent laterality' will refer to preferences that vary from one occasion to another, and 'crossed laterality' will refer to preferences which are different for two of hand, foot and eye (usually hand and eye) measured on the same occasion.

RELIABILITY AND STABILITY OF LATERALITY PREFERENCES

Very few studies of long-term changes in laterality preferences have been carried out. Moreover, the results of any particular study will depend to some extent on the set of measures used and the number of subjects studied.

Gesell and Ames [2] studied seven children up to the age of 10 and found considerable bi-laterality to age 3½, but a predominance of right-handedness from 4 to 10 years. Sinclair [3] looked at 27 children aged 5 to 7 years and after an interval of 3 years found that 12 (44%) had changed hand, foot, or eye preference.

Some short-term studies have shown that differences between the hands in certain motor skills (e.g. strength of grip, peg sorting) prove to be generally unreliable (Provins and Cunliffe [4]), or of only low reliability (Annett, *et al*, [5]), and, consistent with this, correlations between handedness in different skills have been found to be insignificant (Shankweiler and Studdert-Kennedy [6]). But consistency of hand preference for certain single tasks (writing, throwing a ball, using a spoon) is widely found to be fairly reliable (e.g. McFarland and Anderson [7]). The latter is borne out by the NCDS data, studied here, the same hand being used to throw a ball on two occasions by all but 8 of 12,818 children at age 11. Similarly the same foot was used to kick a ball by all but 14 of 12,810 children, and the same eye for sighting through a tube by all but 5 of 12,803 children.

In our study, a general determination of handedness is not attempted partly because the NCDS data is not suitable, and partly because of its dubiety in relation to some tasks. Those who argue for such a general measure have achieved some success, however, and the reliabilities of two well-known handedness questionnaires are of the order .75 to .86 (McMeekan and Lishman [8]). We have confined ourselves to a small number of handedness-specific tasks, however, particularly writing and ball-throwing. We have used these at each age of the NCDS and in the school case studies, with the exception of 16 year-olds in the NCDS, for whom only hand preferred for writing was recorded. The first of the two measures, writing, is susceptible to environmental pressures, but ball-throwing is more likely to develop spontaneously. We recognise that with only two tasks some very small number of children may be misclassified, and that no measure of 'general strength of handedness' can be obtained, but this is countered by the high reliabilities of handedness in the tasks chosen. Of importance for our study are the educational implications that may come from having deviant laterality preferences, and these are likely to be picked up by the tasks used.

As with handedness, different kinds of tests of eyedness have yielded different results. The most effective and reliable of these tests are those of sighting preference, which takes precedence over sensory and accuity dominance (Coren and Kaplan [9]). Eye sighting preferences have been demonstrated in very young infants, children, and adults (Coren [10]), and for a number of difference races and cultures; all give roughly the same distribution of preferences - roughly 62% RE, 32% LE and 3% ME (Poroc and Coren [11]). Right-eyed sighters appear more consistent in their preferences than left-eyed sighters, and so do males compared with females, although there are no sex differences in distribution (Porac and Coren [12]). Sighting preferences are not usually different at near and far distances (Coren and Kaplan [9]). Eye dominance can be changed if sufficient time and effort is expended (Berner and Berner [13]), but the extensive training required and the frequent reports of prolonged subjective discomfort suggest that eye dominance is not merely a casual visual habit, as Gronwall and Sampson [14] have proposed.

Footedness has been much less extensively studied, although it is known that it correlates significantly with handedness (Hicks and Kinsbourne [15]).

Only single measures of eyedness and footedness were included in the NCDS tests at age 11, but these measures were very reliable in themselves (see note on page235). Single measures, however, preclude a 'mixed' category, so that agreement with other tests and test-batteries is likely to be only moderate. However, our experiences with our case study children leads us to expect that these were the best single measures possible.

LATERALITY AND CEREBRAL ORGANISATION

Laterality might be expected to have as little relevance to Mathematical underachievement as eye or hair colour, were it not for the known links between it and brain function.

Evidence of a close connection between hand laterality and cerebral organisation comes from many difference sources : studies of aphasia following brain injuries (Luria [16], Goldstein [17]), results of sodium amytal testing (Rasmussen and Milner [18]), the behaviour of 'split-brain' patients (Gazzaniga [19]), and brain scans of normal individuals (Molfese [20]). Though the results vary slightly from one study to another, it is now generally agreed that in the general population, over 95% of right-handed (RH) subjects have left-hemisphere language processing, the remainder having language processing in the right hemisphere. In contrast, only two-thirds of left-handed (LH) and mixed-handed (MH) subjects have left-hemisphere language processing, the remaining LH and MH subjects dividing equally between right-hemisphere and bilateral processing of language.

Language is, as yet, the only cognitive function to have been localised with respect to hand laterality, but it is generally agreed that in ordinary right-handed individuals certain spatial functions are localised in the right-hemisphere, and certain arithmetical functions in the left-hemisphere. 'Localisation' here does not imply exclusion - it does imply necessity for normal functioning. Thus if certain areas of the 'language hemisphere' are impaired by injury or immobilised by the injection of sodium amytal, language is impaired or made impossible for a time, whereas similar interference with the contralateral hemisphere has no such effects. On the other hand, brain scans have shown both hemispheres to be active during language processing, but with the 'language hemisphere' far more active.

Since motor movements of the limbs are normally controlled by the contralateral hemisphere, it has been suggested that having the dominant hand contralateral to the language hemisphere may be optimal for some language-related behaviours (particularly writing) in that the 'control centres' concerned in their co-ordination will be in closer proximity under that arrangement.

No such simple argument can be applied to eyedness, since information from part of each eye is transmitted to the contralateral, and part to the ipsilateral, hemisphere. In everyday vision, where the information from the two eyes is conflicting or disadvantageous (as in sighting, when a near object is aligned with a distant ogject) that from the non-dominant eye is suppressed. It has been found that in visuo-motor co-ordination tasks (e.g. aiming and shooting with a rifle), having preferred hand and preferred eye ipsilateral is advantageous. The same may apply to hand-foot co-ordination tasks (walking, running). But any links between eyedness or footedness and cerebral dominance are likely to be less direct.

LATERALITY AND ACHIEVEMENT

Claims that 'different' patterns of cerebral specialisation may be detrimental to left-handers (see Kinsbourne and Hiscock [1]) suggest that the aetiology and incidence of left-handedness and other deviant lateralities may be important in the study of learning difficulties in children, both for early prediction of children 'at risk' and for effective remediation.

Agreement is far from universal, but it is significant that while studies of large populations or general samples often fail to find any significant relationship between various laterality variables and educational performance or ability measures (e.g. Rutter, Tizard and Whitmore [21], Clark [22]), clinical samples of 'learning disabled' children are often reported to contain higher than expected proportions of left-handed subjects (e.g. Naidoo [23]). Annett and Turner [24] found some evidence of both findings in adopting different forms of analysis of the same data, though their 'clinical' subgroups were small and the results non-significant. Acknowledging the possibility of some pathological reasons for the discrepancy involving damage to the central nervous system, they favoured an explanation in terms of a combination of accidental variation and the presence of a genetic factor influencing right-handed bias. Absence of this genetic factor, rather than any pathological cause, would then explain at least some of the incidence of left-handedness amongst certain backward groups. A more distinct explanation is made by both Satz [25] and Kinsbourne and Hiscock [1], who emphasise two essentially different kinds of left-handedness, one a 'natural' genetic kind and the other of a pathological nature, the latter accounting for the high incidence of left-handedness in certain clinical populations.

Even when handedness is genetic in origin (and it does tend to run in families), left-handers may still differ from right-handers in the way they transmit and process certain types of information, and this may imply a different educational prognosis - for better or worse. In particular, there has long been some evidence to suggest an above-average incidence of left-handedness amongst groups of poor readers (e.g. Harris [26]).

Whether or not any particular combination of handedness and hemispheric specialisation has disadvantages compared to any other, it has been suggested that subjects may suffer if their cerebral organisation is not well-differentiated, and that left-handers are an 'at risk' category in this respect (Levy [27]). Levy suggests that a lack of specialisation causes inter-hemisphere interference and a corresponding reduction in performance. Some indirect support for this hypothesis, to the detriment of left-handers, has been found in a national laterality study by Calnan and Richardson [28]. Perhaps the strongest suggestion that left-handers are an 'at risk' group comes from Bakan *et al* [29] who propose that all left-handedness is essentially pathological in origin and that trauma occurring at birth can account for most cases.

Clarification of these issues would be easier if lateralisation of language function were as easy to measure as hand preference. But the most reliable measurements (aphasia due to brain injury, 'split-brain' surgical subjects, and sodium amytal tests) can only be made ethically on individuals who for various reasons require brain surgery; and brain scans are also not generally available for normal individuals. If we could ascertain (a) whether right-handers with right-hemisphere language are also over-represented in 'learning disabled' groups, and (b) if the left-handers in such groups have predominantly left, right or bilateral hemispherical language functions, the merits of these various theories would be easier to assess. At present it is difficult to assign differential performance by left-handers to neurological factors or educational provision (for example) with any particular weighting, but any such differentiation of performance would encourage closer scrutiny of both factors.

THEORETICAL CONSIDERATIONS OF LATERALITY

We should make it clear that we are dealing with a number of different issues here which may or may not be connected. Firstly, the hemisphere mainly concerned with language and handedness do appear to be related, as we have seen, but not in any simple way. Secondly, sidedness measures may or may not be related amongst themselves; in fact hand and foot do correlate well above chance level, but hand and eye correlate only a little above chance level given their population distributions, and there is little theoretical evidence to link the language hemisphere with eyedness or footedness. However, some configurations of hand, foot, and eye preferences may be advantageous, and others disadvantageous. (It has, in fact, been shown that having preferred hand and eye ipsilateral is advantageous in aiming and throwing tasks, as already noted on page 238). Thirdly, educational disadvantage, interpreted as lower ability generally, or as specific learning disabilities (two quite different concepts educationally) may be related to hemisphericity, or to laterality preferences, or to both.

As a result of all these possibilities, many theories are generated by researchers in these areas. Many of them being *post hoc* explanations of one-off experimental findings or surveys, and are necessarily to be seen as at best tentative hypotheses. For example, the observation that many pairs of identical twins have mirror-image laterality preferences led to the suggestion that all left-handers are mirror-image twins whose other twin failed to develop (Lauterbach [30]). Most major theoretical orientations are in fact represented. There are theories that handedness is purely environmentally determined (with an environmentalist interpretation of the well-known observation that left-handedness appears to run in families), and that any educational disadvantage to left handers is due to adaptation to and/or pressures to change to a right-handed mode. The most extreme version suggests that hemisphericity can sometimes be changed by a change of handedness (discussed in Goodglass and Quadfasel [31]). On the other hand, there are theories that handedness is all genetically determined, although no pattern of genes and inheritance has yet been put forward that will exactly explain the empirical distributions actually found; again familial left-handedness is cited as evidence. The purely genetic hypothesis also supposes cerebral dominance and any educational disadvantage to be transmitted in the same way. Some genetic inheritance has been inferred for handedness in a cross-fostering study (Hicks and Kinsbourne [15]) and also for eyedness (Brackenridge [32]).

The above hypotheses can clearly be mixed in various ways, and either version can be combined with the maturation hypothesis. This hypothesis is that the specialisation of one hemisphere for language is a maturational process; originally the two hemispheres are equal and language functions develop in both, but gradually one of them takes over as the language hemisphere (Lenneberg [33]). At the same time laterality preferences develop. Both bilateral language representation (associated only with left- and mixed-handers) and weak laterality preferences are then signs of maturational lag, which leads to educational disadvantage. However, the evidence that the neonate brain is already anatomically asymmetrical (Wade *et al* [34]), that its responses are asymmetrically stimulus - dependent as measured by electrical activity recorded from the scalp (Molfese [20]), that infants show asymmetries of head-turning and posture (Liederman and Kinsbourne [35]) and grasping preferences (Petrie and Peters [36]), all point to early specialisation. There is some evidence that skill differences between the hands do develop, and that this is due to differential practice.

The final major group of theories concern abnormal brain development allied to deviant laterality preferences. The strongest form of this position was taken by Bakan *et al* [29], who hypothesised that all left-handedness is pathological and is usually caused by birth trauma. If this strong hypothesis were true we might expect a predominance of left-handers among the brain-damaged, the low ability, and the learning-disabled populations; and this should be clearly seen in any representative sample. The number of findings that run counter to these predictions suggest that the strong form of this hypothesis is not supported. However, after extensive reviews of the literature and a wide range of personal investigations and experiments, both Kinsbourne and Satz subscribe to the view that some left-handedness is pathological in origin, but that familial left-handedness is genetically determined. This would be consistent with both the high incidence of left-handers in clinical groups, and the finding that their average performance in the population is similar to that of right-handers.

THE NEED FOR EMPIRICAL STUDIES

From this brief glimpse of the theoretical jungle, it seems there is a need for empirical studies of large numbers of children and representative 'clinical' groups from large populations, until such time as reliable, non-invasive techniques are available to determine the language hemisphere of normal individuals, and its association with educational achievements.

Although not able to reconcile conflicting theories, evidence from a national sample of over 10,000 eleven-year-old children, from the National Child Development Study, has given some indirect support to the suggestion that left-handers may carry some educational disadvantage (Calnan and Richardson [28]). Their study provides information about children's handedness and its relation to certain social, physical, and achievement variables at age 11, but they do not assess groups who had changed or established their handedness over the previous few years. In relation to educational provision and theories of laterality and hemispheric specialisation, it seems important to establish the pattern of laterality development in young children over a period of time. We have therefore re-analysed the NCDS data to consider the incidence of laterality preferences in children at both 7 and 11 years, and their stability over this period.

LATERALITY DATA FROM THE NCDS

There were several limitations in the data. At most three assessments (tasks, etc.) were used to obtain any single measure of preference (usually two were used) and there were also variations from 7 to 11 to 16 years in the way laterality was measured. The single tasks used to assess eyedness and footedness at age 11 precluded the mixed lateriality category (M) which was available at age 7. The only measurement at age 16 was 'hand preferred for writing', which was a self-report measure (most of the earlier measures were behavioural).

The methods used to determine preferences are summarised in Table 6.1.

For the major part of our analyses we have followed Calnan and Richardson [28] in adopting the mother's report of handedness at age 11. This measure agreed well with the other two measures at age 11; their validity checks included the facts that 21 R-H writers were said

TABLE 6.1

METHODS USED TO DETERMINE LATERALITY PREFERENCES IN THE NCDS

	AT AGE 7	AT AGE 11	AT AGE 16
Handedness	Hand used to draw an X Hand used to throw a paper ball	Mother's report of handedness Mother's report of hand used for writing Hand used to throw a ball	Self-report of hand used for writing
Eyedness	Sighting through a paper tube Sighting through a hole in a card	Sighting through a paper tube	
Footedness	Foot used to kick a paper ball Foot used for hopping on one leg	Foot used to kick a ball	

by mothers to be LH, 5 L-H writers were said to be RH; 25% of reported MH wrote LH and 75% wrote RH; 27.2% (352) of reported LH threw a ball RH and 1.3% (136) of reported RH threw the ball LH; of the 8 children who threw a ball with one hand and then with the other, 7 were reported RH and one was reported MH. The measure also agreed with children's manual dexterity with left and right hands in a square-marking task. Thus there is some validity of the measure. For more consistency of classification from age 7 to age 11, the cases where the mother's report differs from either of the other two assessments at age 11 should perhaps be classified as 'MH'; this group has been treated separately in some of our analyses.

Laterality prevalences, and their consistency from age 7 to 11 were analysed from the NCDS data and are presented in Table 6.2.

DISCUSSION

Handedness

The handedness results at age 11 for the population in our study (containing only those children for whom records were complete at age 7 and age 11) confirm those reported by Calnan and Richardson for a slightly larger subset of the whole 11-year-old population, in which they found 83.8% RH, 10.4% LH and 5.8% MH. The slightly larger population of left-handers in Calnan and Richardson's study indicates that left-handers had less complete records at 7 and 11 than right-handers. The figures confirm that in spite of any pressures to conform to a right-handed norm, sizeable numbers of children are other than right-handed at age 11, with the incidence of left-handed-

TABLE 6.2

LATERALITY PREVALENCES AND THEIR CONSISTENCY FROM 7 TO 11 YEARS

		AT AGE 7 %age of Total Population			AT AGE 11 %age of Total Population			CONSISTENCY %age of 7 yr. olds in Same Category at age 11			CONSISTENCY %age of Total Population
		Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Total
Handedness	RH	79.2	80.3	79.7	81.8	87.5	84.7	94.2	96.1	95.1	74.2
	LH	8.4	5.3	6.9	11.4	7.8	9.6	87.8	80.4	85.1	5.7
	MH	12.4	14.4	13.4	6.7	4.8	5.8	17.3	9.5	13.0	1.5
Eyedness	RE	58.9	60.0	59.5	68.1	68.7	68.4	91.3	90.5	90.9	54.1
	LE	33.7	31.8	32.8	31.9	31.3	31.6	72.4	71.4	71.9	23.6
	ME	7.4	8.2	7.8	-	-	-	-	-	-	-
Footedness	RF	55.0	60.2	57.6	86.1	91.1	88.6	95.4	95.7	95.5	55.0
	LF	8.2	5.6	6.9	13.9	8.9	11.4	57.3	44.6	52.2	3.6
	MF	36.8	34.2	35.5	-	-	-	-	-	-	-

ness higher for boys than for girls (11.4% and 7.8%, respectively).

For those children who are right-handed at age 7, 95.1% are still recognised as right-handed at age 11, and the characteristic is clearly a very stable one. Nearly 5% however have changed from right-handedness, though this may have been influenced by the possibility of some unreliability in the measures. The stability of handedness for left-handers over this period is also high (85.1%), though it is less so for girls than boys - 19.6% of girls and 12.2% of boys changing from left-handedness, possibly because girls tend to conform more to the norm when pressurised. Of those children who were mixed-handed at age 7, however, only 13% (17% of boys and 9.5% of girls) remain so at age 11; here the difference in handedness consistency of boys and girls is statistically significant. The overall number of mixed-handed children also declines markedly over this time from 11.5% to 5.8% of the total population, and the trend at age 7 for more girls than boys to be mixed-handed is markedly reversed at age 11.

Bearing in mind that sex differences may exist in both hemispherical specialisation and in the rate of development of this special functioning (Levy [27]), the figures in Table 6.2 provide pertinent information to link handedness with differential forms of cerebral maturation in boys and girls. In fact, since physical maturation of the brain is generally ahead in girls, the figures at age 7 are the reverse of what we should expect - language lateralisation and handedness should be slower and more mixed in boys, particularly at the earlier age.

The reduction in the number of mixed-handed children and the corresponding increase in right- and left-handedness does give some support to the general concept of 'delayed lateralisation' or 'maturational lag' (or to the role of practice in establishing preferences) and, at least over the age range from 7 to 11, questions the findings of Annett [37], Annett and Turner [24] that mixed-handedness does not decrease with age. Some delayed lateralisation may also be inferred from the large number of mixed-footed (MF) children at age 7, though this may also be due to a lack of differential practice. No mixed-footed category is included at age 11 (as noted earlier, only 14 children out of the population of over 10,000 changed foot in a simple repetition of the test), but the proportions of boys and girls in the RF and LF categories respectively are very similar to those which have emerged at age 11 for handedness.

It is likely that the movement towards right-handedness (and right-footedness) is partly due to socio-cultural pressures and partly due to children's inherent tendencies. For a minority of children, social pressures may outweigh an inclination to left-handedness, and their facility at functioning in a right-handed mode will be relative to the amount of pressure to choose the right hand and the strength of their natural tendency. Some children may retain a left-hand tendency with actual right-hand performance, and this could account for the uncharacteristic 2% to 5% of RH subjects who have R-hemisphere language. This would be consistent with the figures in Table 6.2 where 10.5% of RH at age 11 were not so at age 7, when seen in conjunction with the fact that about $\frac{1}{3}$ of left-handers are thought to have R-hemisphere language.

Footedness, Eyedness and Cross-Laterality

From Table 6.2 we see that laterality in the cases of right-eyed and right-footed children is also a stable characteristic from 7 to 11 years, with consistencies of 90.9% and 95.5% respectively. For left-eyed children, 71.1% remain left-eyed, but for left-footed children only 52.2% are consistently so. By 11 years of age, 88.6% of children have become right-footed (slightly more than right-handed, possibly because there were only two footedness categories), but only 68% are right-eyed. Although the data on eyedness is likely to be less reliable than that on handedness, 77.7% of the population had consistent eye preference from 7 to 11 years, with nearly one-third of the population being left-eyed on each occasion. The stability of the characteristic suggests that it can be a useful descriptor and gives weight to the concept of crossed laterality between hand and eye. Information on crossed laterality is given in Table 6.3.

A sizeable proportion of children, 27% at age 7 and 27.7% at age 11, show crossed laterality of hand and eye, and of these about 60% (16.8% of the total population) show the same characteristic at both 7 and 11 years. In conjunction with Table 6.2 it is seen that 30.6% of right-handers and 37.7% of left-handers have hand-eye crosses at age 7. This result is in broad agreement with that found by Annett and Turner [24] in their analysis of LH and RH groups of young children, but indicates a higher proportion of left-handers. This trend is even more evident at age 11 when 28.1% of right-handers and 40.6% of left-handers have hand-eye crosses.

TABLE 6.3

CROSSED LATERALITY PREVALENCIES AND THEIR CONSISTENCY FROM 7 TO 11

	AT AGE 7 %age of Total Population			AT AGE 11 %age of Total Population			CONSISTENCY %age of 7 yr. olds in Same Category at age 11			CONSISTENCY %age of Total Population
	Boys	Girls	Total	Boys	Girls	Total	Boys	Girls	Total	Total
HAND-EYE										
RH LE	24.7	24.1	24.4	22.6	25.0	23.8	61.1	64.3	62.7	15.3
LH RE	3.4	1.8	2.6	4.7	3.1	3.9	58.8	57.7	57.7	1.5
HAND-FOOT										
RH LF	2.7	2.4	2.5	4.7	3.6	4.2	30.8	12.5	24.0	0.6
LH RF	3.4	2.2	2.8	4.7	3.4	4.1	8.8	22.7	25.0	0.7

Hand-foot crosses are less prevalent and less consistent, though between 1 and 2% of children show a consistent crossed laterality in this respect.

Consistency of Hand Used for Writing

Handedness at age 16 was included only in the form of preferred hand for writing. Of the 12.066 children asked at age 16, 10,671 (88.4%) said they preferred to write RH, 1,363 (11.3%) said LH, and 32 (0.3%) had no preference. 8,970 children had handedness records at all three ages, 7, 11 and 16. Figure 6.1 demonstrates the stability of handedness for writing over the age range 7 to 11 to 16 years. Unfortunately, the mixed-handed category at age 7 cannot be divided on the basis of hand used for writing; it merely indicates that the child wrote with one hand and threw a ball with the other. At age 11 we have used the mother's report of the child's usual hand for writing; here the mixed-handed category was not included.

Thus, 99% of the children who wrote and threw right-handed at age 7 were right-handed writers at age 16; of these 0.35% (25 children) had had a period of left-handed writing at age 11. A further 0.25% of these children (18 cases) could write equally well with either hand at age 16. For the children who wrote and threw left-handed at age 7, 93.2% were left-handed writers at age 16, and a further 0.29% (2 cases) were ambidextrous writers at age 16; 1.3% of these children (9 cases) had had a period of right-handed writing around age 11.

<u>FIGURE 6.1</u>

STABILITY OF HAND USED FOR WRITING FROM 7 TO 16 YEARS

AT AGE 16	7923 RH						1023 LH						24 MH					
AT AGE 11	7879 RH			44 LH			42 RH			981 LH			18 RH			6 LH		
AT AGE 7	R	L	M	R	L	M	R	L	M	R	L	M	R	L	M	R	L	M
	6984	39	856	25	5	14	19	9	14	31	623	327	17	0	1	1	2	3

AT AGE 7	7077 RH						678 LH						(1215 MH)					
AT AGE 11	7020 RH			57 LH			48 RH			630 LH			871 RH			344 LH		
AT AGE 16	R	L	M	R	L	M	R	L	M	R	L	M	R	L	M	R	L	M
	6984	19	17	25	31	1	39	9	0	5	623	2	856	14	1	14	327	3

From 11 to 16 years, hand for writing was very stable, with only 0.52% (42) changing from right hand to left hand; a further 0.23% (18 children) were ambidextrous at age 16. Left-handed writing was less stable, and 4.3% (44) changed from left- to right-handed writing, a further 0.58% (6) were ambidextrous at age 16.

MISSING DATA

Although the number of children with complete records of handedness is much smaller than the number with any record at age 11, the proportions within the handedness groups are still very similar, as Table 6.4 shows.

TABLE 6.4

HANDEDNESS IN MISSING DATA

	PERCENTAGES			
Handedness at age 11 - Mother	LH	RH	MH	N
All children with a record at age 11	10.3	84.0	5.6	13,803
Children with complete records	10.4	83.6	5.9	9,017

In view of the small numbers of children reportedly changing their writing hand between 11 and 16 years, it seems likely that these cases are either mis-reports or children belatedly conforming to, or rebelling against, pressures to use the right hand.

HANDEDNESS, ABILITY AND ACHIEVEMENT

A number of studies (e.g. Rutter *et al* [21], McBurney and Dunn [38], Calnan and Richardson [28]) have considered the relationship between handedness, ability and achievement at various ages, but none have specifically taken into account the degree of consistency or the change in children's handedness prior to the investigation. We are in a position to take account of these variations, and the ability and attainments at age 11 children classified according to their handedness profile from 7 to 11 years of age are summarised in Table 6.5. Handedness is assessed as previously, with one variation. At age 11, the other two handedness variables, mother's report of hand used for writing and the doctor's report of the hand used to throw a ball, are also considered. In view of the exceptionally high agreement between the mother's two reports (Calnan and Richardson [28]), any variation will be largely due to the classification at the medical test. This may introduce unnecessary error variance, but it will identify individuals with some question-mark over their handedness. These have been placed in a separate "imprecise" category in Table 6.5 rather than leaving them in right- and left-handed categories, or combining them with the group positively identified by mothers as mixed-handed.

TABLE 6.5

MEAN ABILITY AND ACHIEVEMENT SCORES BY HANDEDNESS PREVALANCES FROM 7 TO 11 YEARS

Handedness Pattern	Verbal Ability	Non-Verbal Ability	Reading Comprehension	Mathematics Test	η
Consistent RH	22.93*	21.55*	16.44	17.48	7725
" LH	21.59*	20.77*	16.14	16.93	597
" MH	22.41	21.18	16.71	17.67	152
RH at 7 - LH at 11	27.11*	25.89*	19.11	23.79	19
RH at 7 - MH at 11	21.91	20.89	16.39	16.82	375
LH at 7 - RH at 11	21.06	20.27	14.15	16.00	33
LH at 7 - MH at 11	23.34	21.63	16.48	17.20	65
MH at 7 - RH at 11	22.37	20.99	16.21	17.28	874
MH at 7 - LH at 11	21.61	20.13	15.87	16.83	157
Imprecise at 11	21.34*	20.38*	15.63	15.92	397
Whole population	22.70 (s.d. 9.20)	21.38 (s.d. 7.43)	16.37 (s.d. 6.15)	17.37 (s.d. 10.19)	10394

* Denotes significant differences from population mean $\rho < 0.05$.

ABILITY AND HANDEDNESS

Mean scores which are significantly different from the total population means are denoted by an asterisk in Table 6.5. Although the sub-samples are not independent of the finite parent population, a method of direct comparison has been adopted. This avoids the use of a large number of between-group tests, but will have the effect of under-estimating differences between a sample and the rest of the population. Notwithstanding this, a clear difference emerges between the ability levels of children who were consistently right-handed from 7 to 11 years and those who were consistently left-handed. The former have consistently higher mean ability scores (both Verbal and Non-verbal) than the whole population, while the left-handers are significantly lower. The performance of the consistently mixed-handed group lies between that of the other two groups.

The pattern of results shown in Table 6.5 is similar to that obtained by Calnan and Richardson [28] for the total population of 11 year-olds. In general, however, the mean ability level of a group which changed handedness is somewhat lower than that of the corresponding group which was consistent from 7 to 11 years, although most of the results were individually non-significant. Of the four significant results, three involved the two groups of children who had changed to become left-handed at 11. The first, a small group of children (η = 19) who changed from RH at 7 to LH at 11, emerge as being a very able group on both measures of ability. This may be a chance result, but further study of individuals who change their hand preference in this way may be illuminating. The second group (η = 159) who became LH at 11 after being MH at 7 was below average, significantly so in Non-verbal ability, where their mean score was the lowest for any subgroup of the population. The contrast between these groups supports the view that there are many different factors influencing the development of handedness and, taken together with the inconsistent handedness report of nearly 20%, suggests that handedness would be appropriate as a dependent variable, particularly in clinical studies. The 'imprecise' subgroup of children, for whom there was some contradiction in the handedness measures at 11, is significantly below average in ability, both Verbal and Non-verbal, and also lower, though not significantly so, in attainment. It is possible that these low scores may be more collaborative of confusion in taking or reporting on the handedness tests, rather than being related to any 'real' inconsistency in handedness behaviour.

ATTAINMENT AND LATERALITY

Attainment in Reading Comprehension and Mathematics for the different handedness groups follows a very similar pattern to that for ability; but the variances are relatively high, and some of the group sizes are small, so that none of the mean scores are significantly different from the population mean. Although direct comparisons of extreme groups show some significant differences, since these groups are so small the general pattern of results is likely to show a more valid picture of performance than isolated cases.

In their 1976 study, Calnan and Richardson showed left-handers to have lower attainment scores in Reading Comprehension and

Mathematics, significantly so for the former. The present results, although non-significant, agree with this conclusion, with performance levels being generally similar to ability levels. It not surprisingly confirms that, over the whole range of the population, general ability accounts for much of the variance in both Reading Comprehension and Mathematics. Subgroups may have been thought to show up more variations, and in the case of the mixed-handed groups at age 11, there are some changes in the direction of mean attainment compared to mean ability relative to the respective population means. These are slight in the cases of those who had changed hand preference, but the consistently mixed-handed group shows very positive "overachievement" in both Reading Comprehension and Mathematics. This was apparent for Reading Comprehension in Calnan and Richardson's population, but the group's superiority here also extends to attainment in Mathematics. Although the level is not statistically significant, the results suggest that there are no grounds, as far as attainment is concerned, to encourage mixed-handed children to become single handed.

The poorest attainment levels in both Reading Comprehension and Mathematics were shown by the same group, the right-handers at 11 who had been left-handed at 7. Although their ability levels are also among the lowest, their consistently poor attainment is not encouraging, and their Reading Comprehension indicates a good deal of underachievement (although Mathematics achievement was consistent with ability). On the basis of their mean ability, their predicted mean score for Reading Comprehension would be 15.58, but their actual mean score is only 14.15. The group is only small (η = 33) but draws attention to the presence of left-handers in an under-achieving group. The greatest underachievement in Mathematics was shown by the group of mixed-handers at 11 who had been left-handed at 7 (65 children).

Of the larger groups, the consistently cross-lateral group RH x LE was found to be underachieving in both Reading Comprehension and Mathematics.

Cross-laterality does seem to have had some effect on ability and achievement : of the four consistently cross-lateral groups (RH x LF, LH x RF, RH x LE, LH x RE at both 7 and 11 years) only one was on average at or above the expected level in Reading Comprehension, the LH x RF group (η = 66) which also scored significantly above average on the Verbal ability test. On the other hand, only one group was on average below the expected level in Mathematics - the RH x LE group, already mentioned. The LH x RE group was significantly below average on Verbal ability.

Overall the pattern emerging suggests that some decrease in ability and attainment is associated with left-handedness; and that some underachievement may be associated with early left-handedness which later changed to right or mixed. Underachievement also appears to be associated with some consistent cross-laterality patterns.

Although, as in previous studies, the size of differences in mean scores for groups of the whole population are very small, they appear worthy of consideration psychologically and educationally. It is tempting to ignore slight mean differences, or to attribute them simply to social and educational practices which are predominantly designed to cater for right-handed modes of functioning, but, while this may account for some variation, the variation in ability and performance of the laterality groups and the clear sex differences which have emerged, suggest that handedness may not be given the educational attention it deserves.

RELATION TO LEVY'S HYPOTHESIS

The finding (page258) that consistent left-handers are on average lower on both Verbal and Non-verbal ability tests than consistent right-handers would support the hypothesised Verbal or Non-verbal deficit, with equality of the other ability, in left-handers of Levy's [27] inter-hemispheric interference theory. As a further test of this theory we look at prevalence of Verbal-Non-verbal differences in different laterality groups, for boys and girls separately; first for children divided according to handedness at age 11, then for just those groups whose laterality had been consistent from 7 to 11 years. The results are shown in Table 6.6

In Table 6.6, Verbal-Nonverbal differences are raw scores; the population mean Verbal score was 1.18 points above the mean Nonverbal score, and each scale ran from 0 to 40 with means of 22.06 and 20.88, and S.D.S. of 9.36 and 7.61 respectively. It is clear from this Table that in general left-handers are no more liable to have large Verbal-Nonverbal differences than right-handers. There is a tendency

TABLE 6.6

VERBAL-NONVERBAL DIFFERENCES BY HANDEDNESS AT AGE 11

	V-NV DIFFERENCE IN NCDS TESTS										
	< -19	-19 to -15	-14 to -10	-9 to -5	-4 to 0	1 to 5	6 to 10	11 to 15	16 to 20	> 20	η
BOYS RH at 11	0.09	0.84	3.65	12.38	31.29	35.11	13.26	3.14	0.23	0.0	4291
LH at 11	0.0	0.33	3.18	13.71	35.95	33.61	10.54	2.17	0.50	0.0	598
MH at 11	0.28	0.56	4.78	11.52	31.74	31.18	16.85	2.53	0.56	0.0	356
GIRLS RH at 11	0.05	0.18	1.39	8.27	24.64	39.93	20.42	4.54	0.57	0.02	4388
LH at 11	0.0	0.0	1.79	8.21	27.18	34.87	23.71	4.87	0.26	0.0	390
MH at 11	0.0	0.0	2.12	7.63	27.12	37.71	22.03	3.39	0.0	0.0	236
BOYS CONSISTENT RH	0.10	0.85	3.60	12.35	31.36	34.91	13.43	3.16	0.23	0.0	3884
" LH	0.0	0.52	3.12	14.55	36.36	33.51	9.09	2.08	0.78	0.0	385
" MH	1.08	1.08	3.23	8.60	23.66	43.01	18.28	0.0	1.08	0.0	93
GIRLS CONSISTENT RH	0.03	0.21	1.40	8.14	24.36	40.05	20.79	4.43	0.57	0.03	3858
" LH	0.0	0.0	0.93	7.87	27.78	34.72	23.15	5.09	0.46	0.0	216
" MH	0.0	0.0	3.28	9.84	24.59	47.54	11.48	3.28	0.0	0.0	61

Figures are percentages of row total

among left-handed boys for fewer to have a Verbal deficit compared to right-handers, and proportionally twice as many have a Nonverbal deficit of 16 to 20 points (raw scores). Amongst girls, the tendency is for smaller deficits in both directions compared with right-handers. For both boys and girls these tendences are more marked in children whose handedness was consistent from 7 to 11 years.

For mixed-handers, the picture is slightly different; here there is a tendency for mixed-handed boys to have more large deficits in each direction. For mixed-handed girls, there are fewer large deficits, but a slight tendency for small to moderate verbal deficits. In view of the small numbers involved, none of these tendencies should be taken too seriously, unless confirmed in other large-scale studies.

Two further points may be made here; firstly that the above findings relate to the whole population and to handedness *per se* and it could be that for selected ability groups, handedness prevalences may be significant (e.g. Sawyer and Brown [39][40] found differences between handedness groups in reading attainment which were in opposite directions depending on attainment level). Secondly, since handedness patterns do not seem to be related to Verbal-Nonverbal differences, such differences are unlikely to be caused by normal variations in brain organisation such as cerebral dominance.

A similar analysis of Verbal-Nonverbal differences by homolateral and crossed hand-eye preferences also reveals no significant differences between groups. There is a slight tendency among boys for large

Verbal-Nonverbal differences in both directions in the left-handed, right-eyed group. Amongst girls, the tendency is for both crossed groups to have large Verbal-Nonverbal differences in favour of Verbal ability. These findings are shown in Table 6.7.

Differences in the prevalance of large Verbal-Nonverbal differences are at least as pronounced between cross-lateral and homolateral groups as those between left-handers and right-handers. Although differences between handedness groups are in the direction predicted by Levy, these differences are small and statistically non-significant. Moreover, the similar finding of differences between cross-lateral and homolateral groups is not predicted by Levy's hypothesis.

LATERALITY AND NEUROLOGICAL MALFUNCTION

The data looked at so far in this Chapter cannot be directly related to the view that left-handedness is pathological in some cases. There may, however, be some children for whom left-handedness is one factor in a syndrome of neurological malfunction. Our finding in Chapter III of cross-laterality, left-handedness, and other deviant laterality patterns, allied to poor co-ordination and abnormal pregnancy and birth factors in a "hard core" of mathematical under-achievers, together with the finding of deviant laterality patterns in case studies of mathematical underachievers (in Chapters IV and V), and our findings above of underachievement in cross-lateral and other deviant laterality groups in the whole NCDS population, also suggests that we should look at other deviant laterality groups in this connection. The presence of a wide range of medical, social and

TABLE 6.7

VERBAL-NONVERBAL DIFFERENCES AND CROSSED-LATERALITY

CONSISTENT PREFERENCE 7 TO 11 YEARS	VERBAL-NONVERBAL DIFFERENCE IN NCDS TESTS									n
	< -19	-19 to -15	-14 to -10	-9 to -5	-4 to 0	1 to 5	6 to 10	11 to 15	16 to 20	
BOYS RH : RE	0.13	0.73	3.79	12.25	31.61	35.02	12.63	3.49	0.34	2317
RH : LE	0.13	0.77	3.06	12.63	33.29	32.65	14.29	3.06	0.13	784
LH : LE	0.0	0.56	2.23	17.32	35.20	34.08	7.82	2.79	0	179
LH : RE	0.0	0.93	4.13	10.19	40.74	29.63	10.19	2.78	0.93	108
GIRLS RH : RE	0.04	0.22	1.29	8.75	23.93	40.63	20.49	4.11	0.54	2240
RH : LE	0	0	1.41	7.43	24.20	37.00	23.56	5.38	0.90	781
LH : LE	0	0	0.81	8.06	30.65	34.68	20.97	4.84	0	124
LH : RE	0	0	0	5.77	28.85	26.92	28.85	7.69	1.92	52

educational variables in the NCDS data allows handedness to be analysed in relation to some 'clinically' defined subgroups of the population. This idea is now explored further.

INCIDENCE OF DEVIANT LATERALITIES IN SELECTED SUBGROUPS OF THE POPULATION

Calnan and Richardson [28] showed that at age 11 there were no significant differences in laterality preference prevalances among different social classes. Since social class was the single variable found to have by far the largest effect on achievement and ability measures at all ages in the NCDS data (Davie *et al* [41], Fogelman [42]), it is unlikely that differences in ability or achievement between laterality preference groups reflect social background.

In this section we look at two different kinds of special group: the first defined by 'educational' variables and the second defined by 'clinical' variables.

Table 6.8 gives the prevalances of consistent hand preferences and consistent hand-eye crosses for the total population and special groups defined by 'educational' variables. These special groups consist of : "Top ability" children (total ability score > 38), "Bottom ability" children (total ability score ≤ 38), "Top Maths" (Mathematics test score 39 or 40), "Zero Maths" (Mathematics test score zero), "General Underachievers" (Mathematics and Reading Comprehension scores both at least 2 standard errors below expectation based on ability), "SMU" (as defined in Chapter III), "SRU"

TABLE 6.8

LATERALITY PREFERENCES OF SELECTED 'EDUCATIONAL' SUBGROUPS

GROUP	CHANGE OF HAND 7 TO 11 YEARS	CONSISTENT PREFERENCES 7 TO 11 YEARS					η
		RH	LH	MH	RH x LE	LH x RE	
TOTAL POPULATION : BOYS	18.2	72.8	7.2	1.8	13.9	1.8	5656
: GIRLS	19.0	75.6	4.1	1.2	14.2	0.9	5395
TOP ABILITY : BOYS	16.7	74.9	6.7	1.7	13.8	1.6	3201
(TA > 38) : GIRLS	18.3	76.5	4.1	1.1	14.4	0.9	3389
BOTTOM ABILITY : BOYS	20.0	70.1	8.0	1.9	14.0	2.1	2455
(TA ≤ 38) : GIRLS	20.3	74.1	4.2	1.4	13.9	0.9	2006
TOP MATHS : BOYS	17.5	77.5	5.0	0	17.5	0	40
: GIRLS	15.2	81.8	3.0	0	9.1	0	33
ZERO MATHS : BOYS	24.0	62.5	13.5	0	11.5	4.2	96
: GIRLS	27.7	67.7	3.1	1.5	20.0	1.5	65
GEN. UNDERACH. : BOYS	18.1	72.4	7.1	2.4	15.7	1.2	337
: GIRLS	20.5	75.2	3.6	0.7	12.5	0.3	303
SMU : BOYS	21.1	68.4	7.9	2.6	13.2	0	38
: GIRLS	16.9	76.1	5.6	1.4	12.7	2.8	71
SMU* : BOYS	0	33.3	66.7	0	0	0	3
: GIRLS	11.1	88.9	0	0	33.3	0	12
SRU : BOYS	14.0	81.4	4.7	0	20.9	4.7	43
: GIRLS	8.8	88.2	2.9	0	11.8	0	34
SRU* : BOYS	8.3	83.3	8.3	0	16.7	8.3	12
: GIRLS	0	100.0	0	0	25.0	0	4

(defined analogously), "SMU*" (the 'worst' SMUs as defined in Chapter IV) and "SRU*" (the SRUs whose Reading Comprehension scores were furthest below expectation based on ability).

Table 6.8 confirms several impressions which have emerged earlier in this Chapter; especially the different laterality preference distributions throughout most of the 'educational' subgroups for boys and girls. Although the smallness of the numbers makes any firm conclusions impossible, our findings do suggest that future research in this area should treat the sexes separately.

Poor performances in Mathematics, both underachievement and low-achievement, do appear to occur in conjunction with higher rates of cross-laterality, especially in girls. But underachievement and low achievement in Mathematics are distinguished in the case of girls by the prevalence rates of girls who changed hand preference between 7 and 11 years, where the rate is lower than the population average for underachievers but much higher for low achievers. For boys, both underachievement and low achievement imply high rates of left-handedness, these rates being especially high in low achievers.

Table 6.9 gives the incidences of consistent hand laterality preferences for 'clinical' groups selected from the NCDS population. Criteria for the selection of these groups were as follows :

NIND 1 : Chidren who, at the age of 7, had been poorly co-ordinated, as measured by 'slight' or 'marked' ratings by teachers on at least two of the following :

(i) poor hand control
(ii) poor physical co-ordination
(iii) clumsiness.

NIND 2 : Children who, at the age of 11, were poorly co-ordinated, as measured by ratings by doctors and performance tests involving at least four of the following :

(i) some unsteadiness walking backwards on a straight line
(ii) number of squares marked by RH in 1 min. < 70 (mean 89.4)
(iii) " " " " " LH " " < 50 (mean 69.5)
(iv) time to pick up 20 matches with RH > 50 secs (mean 44.1 secs)
(v) " " " " " " " LH > 50 secs (mean 44.4 secs)

BIND : Children whose birth data had included at least four of the following :

(i) abnormal method of delivery
(ii) abnormal pregnancy
(iii) foetal distress at birth
(iv) mother's age $\leqslant$ 19 or $\geqslant$ 40
(v) gestation period $\leqslant$ 36 weeks or > 42 weeks.

EIND : Children who, at the age of 11, scored in the top 25% of the population on ratings by teachers of at least five of the following emotional behaviour variables :

(i) Unforthcomingness
(ii) Withdrawal
(iii) Depression
(iv) Anxiety towards adults
(v) Anxiety towards children
(vi) Hostility to adults
(vii) Hostility to children
(viii) Writing-off of adults.

VAR163 : Children who at the age of 11 had a score of 40 or more on the Bristol Social Adjustment Guides.

SYN : Children who at the age of 7 had scored a total of 30 or more on the Bristol Social Adjustment Guides.

From Table 6.9, we can see that compared with the total population, there were relatively more girls with anomalous consistent lateralities or changes in laterality of hand preferences among the 'neurological groups' (co-ordination, birth factors). On the other hand, in two out of three of the 'emotional' groups (emotional variables, behaviour ratings) there were fewer such deviant preferences.

However, for boys the picture was different, with increases in both consistent left hand preferences and more changes of hand preference tending to be associated with both 'neurological' (especially birth factors) and 'emotional' variables at 11 years (but not at 7 years).

These data therefore give slight support to our hypothetical causal links between neurological factors and laterality preferences, and between laterality preferences and underachievement; they also serve to emphasise some of the differences between boys and girls which we feel should be taken more into account in investigations of the role of laterality in learning disorders.

TABLE 6.9

HAND PREFERENCE CONSISTENCIES OF CERTAIN 'CLINICAL' GROUPS

GROUP	N	SEX	CHANGE OF PREFERENCE	CONSISTENT PREFERENCE		
				RH	LH	MH
NIND 1 ≥ 2	899	BOYS	20.4%	69.0%	8.3%	2.3%
	412	GIRLS	21.8%	69.7%	6.6%	1.9%
NIND 2 ≥ 4	79	BOYS	20.3%	72.2%	7.6%	0
	70	GIRLS	24.3%	70.0%	2.9%	2.9%
BIND ≥ 4	52	BOYS	21.2%	67.3%	9.6%	1.9%
	47	GIRLS	19.1%	70.2%	8.5%	2.1%
EIND ≥ 5	67	BOYS	19.4%	71.6%	9.0%	0
	28	GIRLS	17.9%	78.6%	3.6%	0
VAR 163 ≥ 40	47	BOYS	23.4%	63.8%	10.6%	2.1%
	12	GIRLS	25.0%	66.7%	0	8.3%
SYN ≥ 30	41	BOYS	19.5%	73.2%	4.9%	2.4%
	15	GIRLS	6.7%	93.3%	0	0

OVERALL CONCLUSION

Both our large-scale investigation, using the NCDS data, and (especially) our case-studies in local schools have supported the idea of links between laterality preferences and mathematical underachievement. In the former we found that cross-laterality of hand and eye in the case of girls and left-handedness in the case of boys occurred with frequencies higher than those for the whole population among mathematical underachievers. In our case studies we found that cross-laterality and non-right preferences were more prevalent than those for the NCDS population.

We have also found some slight support for our hypothesis that these links are mediated by neurological factors which give rise to both the pattern of laterality preferences and the mathematical difficulties which lead to the underachievement.

Our analysis of the NCDS data showed that for both boys and girls left- and mixed-handedness and change of hand preference from 7 to 11 years tended to be more prevalent among some 'neurological' groups (birth factors, poor co-ordination); and this finding was also supported in the literature.

Our investigations suggest that further research into this area will be worthwhile.

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CHAPTER VII

SHORT-TERM MEMORY

Short-term memory as part of the memory system is introduced together with some known characteristics. Investigations of short-term memory in connection with learning difficulties and studies of the role of short-term memory in Mathematics are presented from a study of the literature. Case studies of children in local schools, and interpretations in terms of a short-term memory deficit, are then presented. Finally, links between short-term memory and other aspects of brain behaviour are discussed.

In Chapters IV and V we saw from the results of our investigations of mathematical underachievers in local schools that some of these cases could best be explained in terms of poor memory. In conjunction with their poor performance on the Digit Span task, this suggested that a short-term memory deficit might be involved in some cases of mathematical underachievement. In this Chapter we investigate the evidence for this via our case studies and the literature, and we consider short-term memory deficit as a neurological impairment. We begin with a general study of short-term memory.

SHORT-TERM AND LONG-TERM MEMORY

Current studies of memory usually employ information-processing models. That is, man is regarded as an information-processing organism : information is taken in via the sensory organs, passed along nerves to the brain, selectively retained or discarded, integrated, processed, and then stored, discarded, or acted upon. These models of memory distinguish at least two constructs, short-term memory (STM) and long-term memory (LTM), as distinct characteristics of the memory system. STM is the system which stores information for current attention and in which actual information-processing is carried out; LTM represents the products of more 'digested' experience or knowledge.

Since Miller's [1] experiments reported in 1956, it is widely accepted that the amount of attentional energy, or capacity, available to STM is severely limited, so that only a few storage and processing activities can be carried out simultaneously. On the other hand, the capacity of LTM is very large (a different dimension altogether), and the knowledge stored ranges from the particular, such as individual letter and name codes, to the general, such as strategies for processing and maintaining information. The two constructs, STM and LTM, are given very different natures which give rise to different insights into the memory process.

In the cases of the mathematical underachievers who instigated this investigation of memory, we have no reason to suppose that LTM was in any way abnormal. On the contrary, the fact that the two sixth-formers concerned had done well in 'factual' subjects needing long-term storage and retrieval of information, suggests that LTM was efficient and above average in these cases. This made their poor performances on the Digit Span task even more remarkable. We shall not, therefore, analyse LTM further, but concentrate on STM.

SHORT-TERM MEMORY

In his 'scientific' studies of memory published in 1885, Ebbinghaus demonstrated the different time-scales and capacities of STM and LTM. He could learn item lists of almost any length, given time, and reproduce them perfectly at a much later time (from LTM), but the maximum number he could reproduce perfectly immediately following a single presentation was generally seven, with remarkably few exceptions. This latter measure, characteristic of STM, is generally known as the memory span (MS). Jacobs [2] and Galton [3], respectively, investigated developmental and individual differences in memory span, and both found a relationship between span and mental ability. MS was soon a common component of mental ability assessments (Binet and Henri [4]). A detailed account of memory span was given by Miller [1] in 1956, entitled "The Magical Number 7 ± 2", showing that Ebbinghaus' seven was still the established norm.

From the beginning of the 1970's, when interest in sources of individual differences rekindled, and detailed information-processing models of cognition were developed, the focus of studies of memory span shifted from the empirical to the theoretical with an explication of underlying processes. This goal is far from being achieved, but, as we shall see later, some progress has been made. One model of STM which commands a large measure of support, and accounts for a wide range of experimental findings, is that developed by Baddeley and Hitch [5]. This will now be described briefly, as some of the experimental findings discussed later are interpreted in terms of this model.

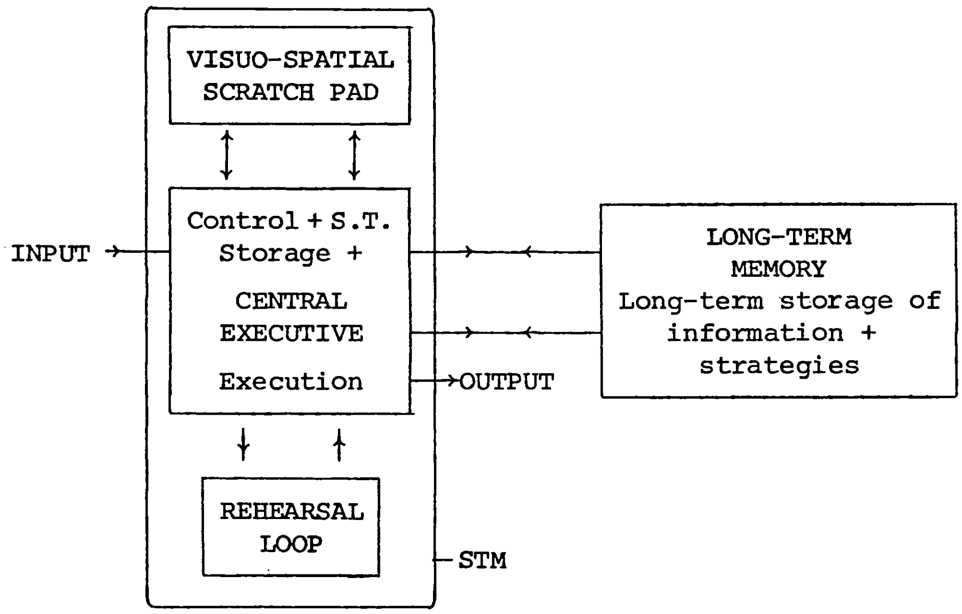
THE INFORMATION-PROCESSING VIEW OF STM : BADDELEY AND HITCH'S MODEL

According to information-processing theorists, STM is used not only to store small amounts of information for short periods of time, but also as a working store for cognitive tasks such as problem-solving, speech comprehension, mental arithmetic, and reading. This view was built up from the empirical evidence, and also appears to have been influenced by the analogy with models of computers and other "thinking machines", and reinforced by experimental evidence designed to test various aspects of the model. Thus Baddeley and Hitch [6] showed that the more items of information a subject was required to store temporarily, the more interference was caused to the simultaneous execution of a cognitive task. This demonstrates the intimate connection between short-term storage and cognition. However these experiments also showed that, even when holding a set of items nearly equal to his memory span, a subject was still able to perform the cognitive task, although inefficiently. They interpreted this to mean that the processing part of STM cannot all be used to increase storage, even when the storage part is overloaded.

The intimately-connected, yet separate, functions of short-term storage and cognitive working-store have led Baddeley and Hitch along with several other theorists (e.g. Atkinson and Shiffrin [7]) to propose that STM consists of at least two different parts : a control system, or 'central executive' (in B & H's model), and a storage system, or 'rehearsal loop' (in B & H's model). The items in the latter are inferred from experimental evidence to be maintained by rehearsal, and kept in a phonological code, under the control of the central executive. Based on experiments with visuo-spatial material, Baddeley and Hitch have also added a "visuo-spatial scratch pad" to this basic system. The visuo-spatial scratch pad is inferred to hold a limited amount of information (similar to the rehearsal loop) in a visuo-spatial code, and is also under the control of the central executive (see Figure 7.1).

FIGURE 7.1

BADDELEY AND HITCH'S MODEL OF SHORT-TERM MEMORY



TWO EXPERIMENTAL MEASURES OF MEMORY SPAN

In the literature on Short-term memory, we find that Memory Span is measured in two essentially different ways.

The traditional way is to start with two or three items (digits, letters, words, etc., each of which gives a particular form of memory span, i.e. digit span, letter span, word span, etc.) for presentation, which the subject is required to repeat back in the same order immediately after presentation. The number of items presented is gradually increased until the subject reaches a ceiling in errorless recall. The maximum number of items which the subject can repeat back in this way, without error in at least 50% of presentations, is then his memory span. The items are presented at a uniform rate of one per second in standard presentation. This is the memory span task.

A different measure of 'memory span' is arrived at by presenting a number of items (digits, letters, words, etc.) sufficient to exceed memory span, and measuring the number or percentage of items accurately recalled, averaging over a number of trials. This is the supra-span task.

Scores on the memory span task and on the supra-span task, however, are far from perfectly correlated (Lyon [8]). It has been conjectured that they may reflect different processes or different combinations of processes (Watkins [9]). This seems a reasonable conjecture, since the tasks impose slightly different requirements, the memory span task requiring items to be repeated back without omissions and in the same order. Moreover, the digit-span measure is impracticable in the supra-span task because of the limited number of different digits. There is also a slight difficulty associated with the supra-span measure : the treatment of errors. On the one hand, credit is to be given for items accurately recalled, but on the other hand should equal credit be given to recall with some false items (i.e. not among those presented) as to recall with no false items? The memory span task raises no such dilemma since omissions and wrong orders require the experimenter to ignore them and any subsequent items in measuring memory span. Reversals of order are then an indication of temporal order difficulties in the subject, which may lead to an underestimate of the number of items actually recalled. Each of these measures thus has its strengths and its weaknesses. We have preferred the more established memory span task, which is also used in ability test batteries (WISC, WAIS, British Ability Scales) in the form of the Digit Span measure.

THE MEMORY-SPAN TASK

Intuitively the memory span task is fairly simple; the number of steps to solution are few, knowledge requirements are minimal, and transformational requirements are also minimal. The task is easy to administer, performance is highly quantifiable, and measurements are reliable. Moreover, it is a test of optimum performance, assumed to measure some basic attribute of intellectual functioning. In support of the latter assumption is the empirical evidence that digit span (memory span using digits as the presentation items) correlates with intelligence scales (Matarazzo [10], Jensen in Dempster [11]) and achievement and aptitude measures (Dempster and Conney [12]). Growth in memory span also parallels aspects of psycholinguistic development and Piagetian development, in the sense of improved scores on Piagetian tests of concrete and formal reasoning (Brown and Fraser [13], McLaughlin [14]).

The development of memory span with age and ranges of individual differences at given ages are shown in Figures 7.2 to 7.4 (taken from Dempster [15]).

FIGURE 7.2

DEVELOPMENTAL DIFFERENCES IN DIGIT SPAN

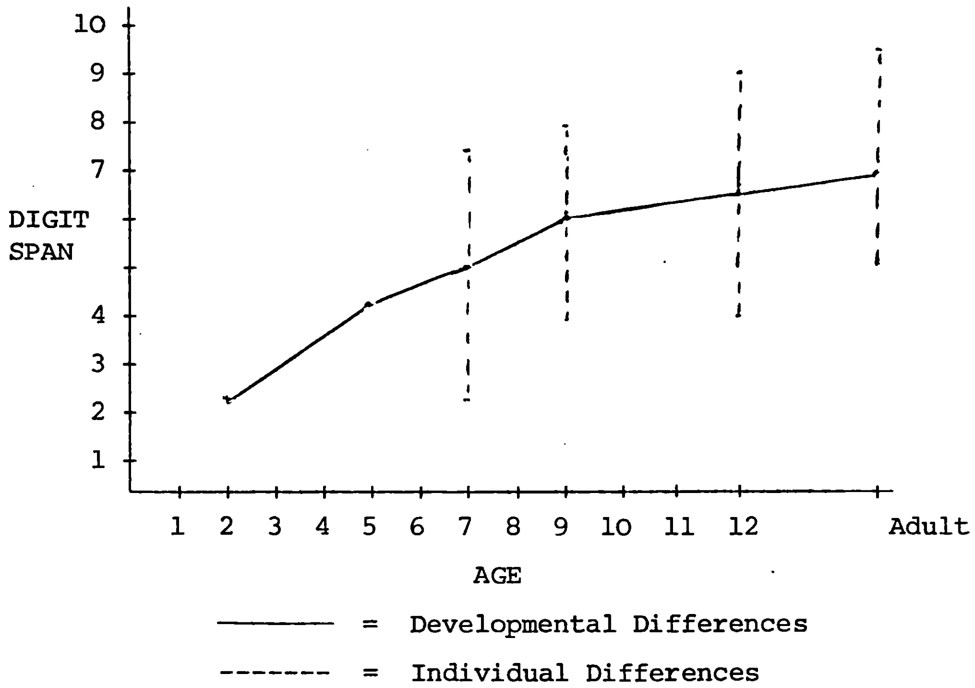


FIGURE 7.3

DEVELOPMENTAL DIFFERENCES IN WORD SPAN

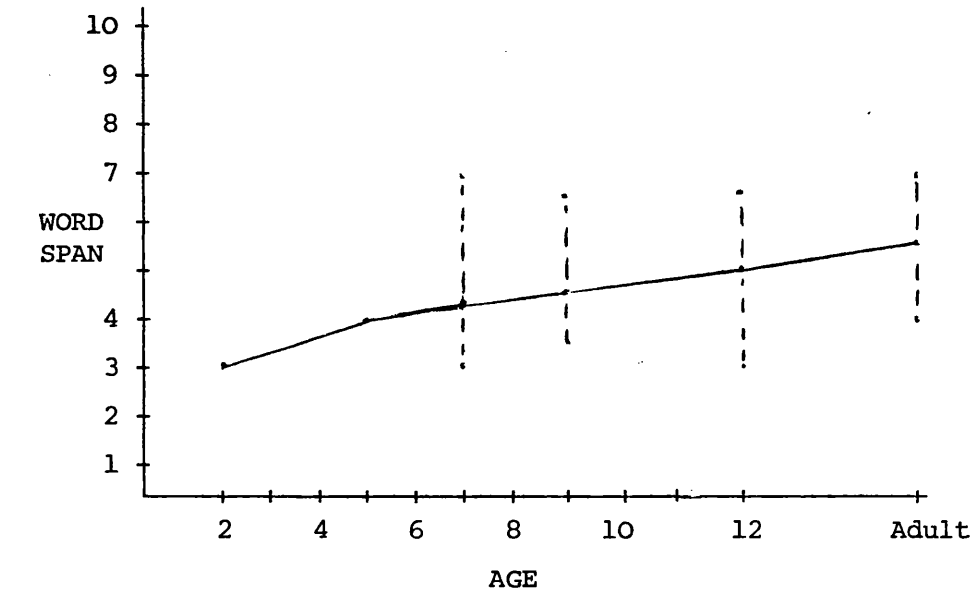
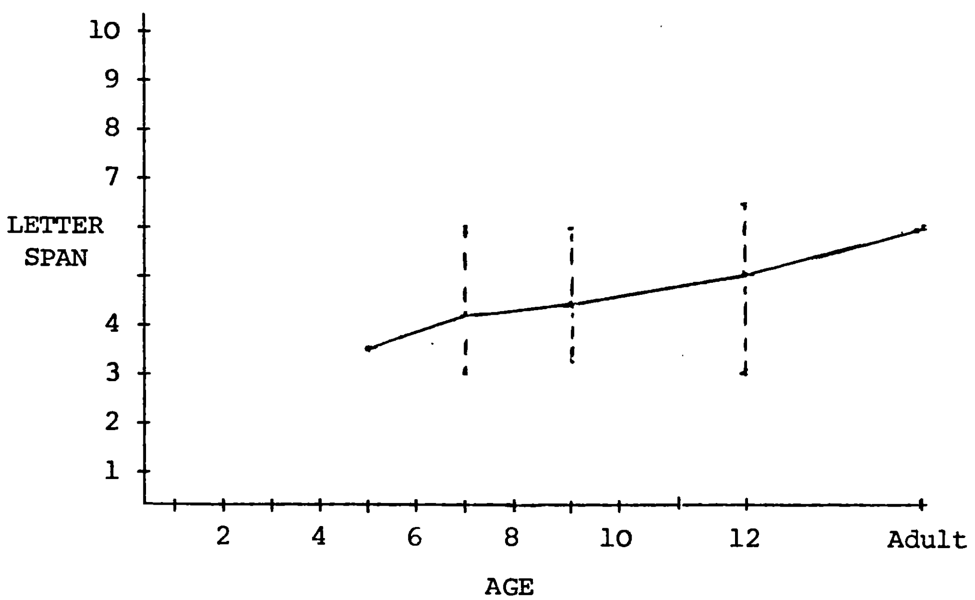


FIGURE 7.4

DEVELOPMENTAL DIFFERENCES IN LETTER SPAN



Mention should be made of some variations of the memory span task. In the backward memory span task the procedure is the same as in the memory span task except that the subject is required to repeat the items back in the opposite order to that in which they were presented. This measure correlates even more highly with intelligence test scores than does the memory span (Matarazzo [10]). This is presumably because the backward memory span task, as well as involving the perception and recall of temporal order, requires a transformation of the material to be recalled; that is, the reversal of the temporal order. The ability to perform this transformation is a measure of cognitive functioning which appears to be more closely related to general cognitive functioning than the memory span task itself. The backward span measure is usually found to be one or two items shorter than the forward span measure, for a given subject. This probably indicates the additional load imposed on STM by the transformation required in the backward span measure. In some ability tests (e.g. WISC) it is usual to combine the two measures; while it is true that both appear to contribute to general ability, the differences between the two measures, and their possible contribution to diagnosis of more basic problems in learning disorders, suggest that they should be kept separate.

It is clear that both measures are relevant to mathematical problem solving, which usually involves the active retention in STM of numbers to be operated on, operations to be used, strategies or algorithms being used, and the point reached in such a strategy or algorithm, as well as the ability to perform transformations concurrently with retention of this material.

Another variation in the memory span task is to change the mode of presentation and/or response. Thus items may be presented visually or haptically, and output response may be spoken, written, or motor (tapping). Other variations include changing the type of material presented, or the presentation rate. Since the verbal presentation/verbal response mode is the one most thoroughly investigated and has well-known norms for a variety of different groups; and since the digit span test is the most common and best-researched presentation material, we have used the standard digit span (forward and backward) tasks in our researches.

Relations between these variations and experiments shedding light on the functioning of STM are now described.

REVIEW OF RESULTS OF SOME EXPERIMENTS IN SHORT-TERM MEMORY

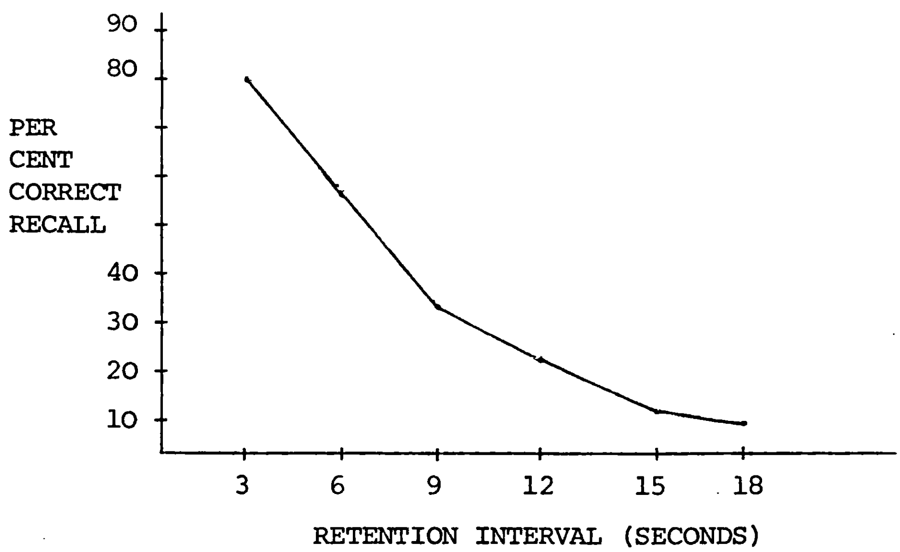
Three areas will be considered : results which apply to the general population (experiments using normal subjects, random samples, etc.) in order to look at properties of STM in general; results which apply to developmental differences (experiments using different age groups) in order to look at properties of STM which change with age; and results which apply to individual differences (experiments using high- and low-memory span groups, etc.), particularly to look at characteristics of low-memory-span groups.

GENERAL POPULATION EXPERIMENTS

In general, if a series of items can be repeated back accurately immediately after presentation, it can be repeated back accurately at any later time, provided the subject is free to rehearse between presentation and recall. This is thought to be achieved by use of the rehearsal loop under the active control of the central executive. However, if a mental task is imposed on the subject between presentation and recall, then the material in the series is rapidly forgotton, as Figure 7.5 shows (Peterson and Peterson [16]). In this case the

FIGURE 7.5

PERCENTAGE FREQUENCY OF COMPLETELY CORRECT RECALL OF 3-CONSONANT TRIGRAMS



central executive is engaged in both active control of the rehearsal of items to be rememberd and in the execution of the mental task, and there is interference between these two activities. Moreover, forgetting is more rapid with visually or haptically presented material than with aurally presented material. This leads to the finding that recall is superior for aurally presented material whatever form of output response is required (Payne and Holtzman [17]).

We must emphasise that results in this section apply only to the 'normal' population. For some groups such as certain types of learning-disabled children or some individuals suffering from brain damage or certain 'old-age' syndromes, etc., some of these results will not hold. For example, the superiority of recall of aurally presented material does not hold for some learning-disabled children.

Presentation rate affects the number of items accurately recalled. In general, there is a slight decline in numbers recalled from very fast rates to the standard rate of 1 item per second, followed by an increase. Presumably at first there is little opportunity for the employment of conscious strategies and forgetting increases with storage time, but at slow rates of presentation strategies such as rehearsal and "chunking" (i.e. the amalgamation of several individual items into a single compound item, such as the digits 7, 2 into the number 72) allow improved performance.

As we have already mentioned, the capacity of STM, or 'working memory', is greater than the memory span, since problem-solving can take place concurrently with holding a number of items up to the memory span in store. However, when the number of items concurrently held progresses beyond three, interference in the problem-solving task increases rapidly. Baddeley and Hitch interpret this as restricting the rehearsal loop to about three items, the remaining items in store being maintained by the central executive at the same time as monitoring the problem-solving task. This effect holds across a number of tasks; Baddeley quotes a verbal-learning task, a prose comprehension task and a free-recall learning task.

The capacity of the rehearsal loop was estimated by Baddeley, Thomson and Buchanan [18]. They showed that when subjects were given lists of five words, their immediate recall declined linearly with the number of syllables in the words; that is, it depended linearly on the reading rate (words per unit time). Moreover, the word-length effect disappeared when articulation was suppressed by getting subjects to count repeatedly up to six during presentation. Finally, using words with the same number of syllables but different articulation items, the latter was found to be the crucial variable. These authors concluded that the rehearsal loop is time-based and its capacity depends on articulation time of the items held rather than on the amount of information or the number of items.

In an investigation of working memory, or STM, in mental arithmetic, Hitch [19] showed that loss of information is time-dependent; that is, the longer a partial result is held in memory before being recorded or used, the greater the probability that it will be erroneously recorded. This direct demonstration is what would have been predicted from the results of the Peterson and Peterson experiment described on page 285.

DEVELOPMENTAL DIFFERENCES

As Figures 7.1 to 7.3 show, memory span increases with age. This used to be attributed to an increasing memory capacity, but recent experiments shed doubt on such an interpretation.

Nicholson [20] starts with the results of Baddeley, Thomson and Buchanan, quoted above, and Watkins' [9] finding that memory span is greater for more familiar than for less familiar words. Observing that, for adults, Baddeley *et al* found the linear relationship :

$$MS = k \cdot RR + c$$

where MS = memory span, RR = reading rate, k = a constant with the dimensions of time ($\sim$ 1.87 secs) and c = a constant near zero, Nicholson interprets reading rate as an index of processing speed and k as an index of capacity. He obtained a similar linear relationship between MS and RR using children of 8, 10 and 12 years. Combining both sets of results, he concluded that, for any given reading rate, memory span is independent of age, and that observed changes in memory span with age are entirely due to increases in reading rate which he interprets as processing speed. (Note that only group means were used - this still leaves individual differences which may well reflect individual capacity differences as well as differences in individual reading rates. Nicholson suggests the use of Baddeley *et al*'s method to obtain individual estimates of slope (capacity) in order to compare individual capacities.)

In another developmental study, Dempster [21] used the memory span task with different types of material and children of mean ages 7, 9 and 12 years. Age differences were strongly affected by type of material; where "chunking" strategies (page 286) were made improbable (such as with consonant letters and carefully selected words) age differences were negligible; where such strategies were more easily employed (consonant-vowel pairs) age differences were larger. He also found that age differences were affected by method of presentation, i.e. blocks of similar material or alternation of material, and by stage of practice (first or second half of testing time). These results also suggest that memory capacity may not change with age; but it suggests that increased use of memory strategies, rather than increases in reading rate, may be responsible for the observed increase in memory span with age.

INDIVIDUAL DIFFERENCES

In a later article, Dempster [15] examined four strategic (rehearsal, grouping, chunking, retrieval strategies) and six non-strategic (item identification, item ordering, capacity, susceptibility to interference, search rate and output buffer) variables sytematically via reported experimental results in order to estimate the range of individual and developmental differences in memory span associated with each variable, and to examine each one's claim to be a source of span differences. He concluded that only the non-strategic variable, item identification, appears to be a major source of differences, but that item ordering and susceptibility to proactive interference are possible sources, and that evidence on the output buffer and capacity is largely negative. Further, he concluded that none of the strategic* variables appear to be implicated. He concluded that the most important factor seemed to be the speed with which incoming items can be identified.

An interesting theory proposed by Chase (quoted in Dempster) is that the underlying basis of speed differences is myelinisation, since myelin is known to affect neural conductivity. This would certainly put memory on a biological and neurological basis, but, so far, is just speculation.

Chase, Lyon and Ericsson [22] examined the correlation between memory span and the speed of manipulation of symbols in STM. Most of the estimates of processing speed did not correlate with memory span, and they concluded that MS is not determined by the speed of symbol manipulation. They showed that MS and rehearsal rate are not related for lists of digits of length below memory span; but as list length increases, low memory span leads to difficulties in remembering, which leads to lowered rehearsal rates.

To sum up this review of STM, we have seen that there is a limit to the number of items that can be maintained in short-term memory, that this number depends on the type of item and the presentation rate. Recall declines with time if a mental activity requiring active processing is interposed between presentation and recall; although a

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* Here we are considering differences between individuals. We have seen earlier that within the individual strategic variables probably explain span differences for different presentation rates.

number of items equal to the memory span can be remembered concurrently with the execution of a problem-solving task, but only at the cost of considerable interference in the execution of the task. In particular, mental arithmetic is susceptible to these effects. Memory span increases with age, although this is probably not due to any increase in memory capacity, but to more efficient use of that capacity either by increases in articulation rate (enabling more items to be held in the time-based rehearsal loop) or by more efficient strategies for coding items into the rehearsal loop. Individual differences do not appear to be due to strategic variables, but primarily to speed of identification of incoming items as they are presented. This all tends to imply that any deficit in STM is a characteristic function of the brain, rather than a result of learning.

STM AND LEARNING DISABILITIES

We have found some tentative empirical links between STM and mathematical underachievement and there is a growing body of knowledge which suggests that in general learning-disabled children, as a group, have lower memory spans than normal children of the same age. The latter applies also to studies which have tried to equate for intelligence (although, as S-T memory is tested in most clinical IQ assessments, including the most widely used instruments - the WISC and Stanford-Binet - we may question their success). Associated with these findings of lower memory spans in learning-disabled groups, a number of other phenomena have been recorded. For reading retardates, Liberman [23] found that the usual clear phonemic similarity effect with visually presented letters was absent. (There is usually a decline in accurate recall of visually presented letter strings when the letters in the string have phonemically similar names, e.g. B C D E G P T V than when they are different, e.g. C O Q, even though the latter may be more similar visually. This is interpreted as reflecting the phonological code in which items are stored in the rehearsal loop). Also for reading retardates, Bakker [24] noted the excessive number of order errors in memory span tasks. As we have already remarked, order errors may reflect a difficulty with temporal order rather than a storage difficulty *per se*. Naidoo [25] found a relationship between low digit spans and dyslexia.

Torgesen and Houck [26] compared three groups of eight children: learning-disabled children with low digit-span scores on the WISC-R, learning-disabled children with normal digit-span scores on the WISC-R and a normal control group. They performed a series of experiments with these 24 children over an eight month period. Long- and short-term stability of digit-spans scores showed that the LDs with poor digit spans were more consistent in span scores over both long- and short-terms, the scores of the other two groups declining over time; and the variability in recall scores was least for the same group. Incentives to improve their performance had no effect on LDs with poor memory spans but removed the short-term decline in scores of the other two groups. Variations in presentation rate from 4 per second to 1 per second showed a slight decline in recall for all groups, then there was the usual rise in score when presentation rate was decreased from 1 per second to 1 per 2 seconds for the control group, but the scores of both LD groups fell. Experimenter-imposed chunking of digits showed improved scores for all three groups; there was no carry-over effect on any of the groups on a return to normal presentation.

Conjecturing that an attentional deficit might underlie poor span scores, the authors asked the children to detect a critical digit pair in a string of 18 digits presented similarly to the digit span task. They found that LDs with poor digit spans performed approximately as well as members of the other two groups. In a further measure of attention, the children listened to a presented string of digits and marked H for digits 6 to 9, L for digits 1 to 4 as they were presented. At 1 digit per second there was no difference between the three groups, but for faster presentation, 2 digits per second, both LD groups were significantly worse than controls, while for slower presentation the LD low-digit span group was worse than the other two groups.

When the usual digit-span procedure was altered by requiring the children to repeat each digit as it was presented, recall of the LD low-digit span group was unaltered, while the other two groups performed worse, but still significantly better than the former. Testing with different stimulus materials (one-syllable animal names, nonsense syllables) showed no significant differences between the groups for nonsense syllables, that all groups scored higher on words than on nonsense syllables, but the LD low-digit span group less so than the other two groups, and this group showed no improvement in scores from words to digits, whereas the other two groups did.

Finally, naming rates for digits and for animals were measured for each group. Statistically the naming rates for digits were not significantly different, although they were much more variable for the two LD groups, but the LD low-digit span group was much slower than the other two in naming animals, and much more variable.

These experiments together suggest that inefficient control processes cannot account for the poor performances of the LD low-digit span group, and that a structural deficit is likely. For, these children appear to have been as attentive as the other groups, they could not respond to incentives, they did not lack strategy in comparison with the other groups (since imposed strategy improved performance of all groups); on the other hand, they responded abnormally to changes in presentation rates, showed no effect of verbalisation during the digit span task, showed decreased effects of variation in stimulus material, and had low naming-rates for common words (animal names). The last two experiments suggest that such a structural deficit may take the form of a deficit in the availability of coding information from long-term memory, rather than a deficiency in the operation of the articulatory loop.

In a review of specific reading retardation and working memory, Jorm [27] first examined the possibility that retarded readers have a deficiency involving either the operation or the utilisation of the articulatory loop. Such a deficiency would lead to differences in performance with respect to (a) the retention of small amounts of verbal information for brief periods, i.e. memory span; (b) retention of the serial order of items in such tasks; (c) the occurrence of phonological confusions; (d) the use of verbal rehearsal. Examining each of these predicted outcomes in turn, he showed (a) that retarded readers do perform poorly on memory span tasks in general, but quoted the Torgeson and Houck study in which a group of retarded readers did have normal digit spans. Moving onto serial order, (b), he quoted studies by Bakker [28], Corkin [29] and Mason *et al* [30] which, between them, found deficiencies in order memory for verbal and non-verbal (but verbally codeable) items presented visually, haptically, or aurally. But he noted that these studies may have confused order memory with item memory, and that in the study by Hulme [31], in which order memory and item memory were separated, no order deficit was found. Jorm then went on to show that studies of phonological confusions, (c), indicate that, for younger readers, such confusions are less common in retarded readers. But for older retarded readers (adults and adolescents) phonological confusions were similar to those of normal 8 - 9 year-olds matched for error rates on the memory task. Finally, he concluded that the weight of evidence on the use of verbal rehearsal, (d), indicated that retarded readers make less use of it than do normal readers. However, there was some evidence that they do use rehearsal as a strategy and can increase the use of this strategy somewhat if given appropriate instructions. Jorm concluded that there is a failure by retarded readers to use the articulatory loop adequately, which could be due to a structural problem in the transfer of information to the articulatory loop, or to deficiencies in control of the loop by the central executive, or to the unavailability of adequate phonological coding information in long-term memory, the latter being a similar conclusion to that of Torgesen and Houck (on page 294).

Moving on to a consideration of the visuo-spatial scratch-pad, and noting in passing that retarded readers have normal iconic storage, Jorm first discussed the difficulty of finding stimuli which cannot be verbally recoded. He concluded that :

> "when attempts have been made to control for verbal coding, most studies find no difference between normal and retarded readers, although this finding is not universal. In view of the persistent doubts about the possibility of verbal coding in these discrepant studies, the tentative conclusion must be that no visuo-spatial short-term memory deficit has been shown to exist in retarded readers. The consistently negative findings on long-term visual memory in retarded readers, ..., reinforce this conclusion."

He further concluded that Hulme's [31] experiments on motor memory indicate that retarded readers have normal short-term memories for motor patterns.

Summing up, Jorm found that there is mounting evidence that the short-term memory deficit in retarded readers is not due to selective attention. However, on control processes, Jorm concluded that although retarded readers appear to have no difficulty in attending to the relevant aspects of memory tasks, there is evidence that they fail to make adequate use of mnemonic strategies such as verbal coding, rehearsal, and organisation. Such deficiencies in control processes could be partly responsible for their failure to use the articulatory loop adequately, although the studies by Cohen and Netley [32] and Torgensen and Houck [26] indicate that other factors are involved. He saw as another explanation the possibility that both difficulties in utilising the articulatory loop and the inadequate use of strategies could be due to the unavailability of appropriate information in long-term memory.

In support of the latter hypothesis, Jorm went on to review studies of long-term memory in reading retardates. He found that studies of non-verbal long-term memory give a consistent result of no differences in performance between retarded and normal readers. Moreover, he found reasonably consistent evidence that retarded readers can adequately encode semantic information (e.g. word meanings) in long-term memory, but strong evidence that they tend to have difficulties in storing phonological (the sounds of words) information, and are slower to retrieve such information. He surmised that the slow retrieval of overlearned phonological information by retarded readers possibly reflects problems in the initial storage of such information.

If the STM deficits of mathematical retardates are similar to those of reading retardates, Jorm's finding that control processes account for some of the deficit in the latter gives hope of some remediation by the simple expedient of teaching mnemonic strategies with adequate practice in using them.

Most of the studies of memory in learning-disabled children have been concerned with reading and language disabilities. An exception is a study by Webster [33], in which he compared American 10-year old Maths-proficient, Maths-deficient and Maths-severely-deficient groups on memory tasks using auditory and visual presentations. Mean memory span declined with mean Mathematical ability of the groups (as measured by the Wide Range Achievement test, i.e. largely arithmetic). Average memory span was lower for visual than for auditory presentation in the Maths-proficient (normal) group (as is usual), but the reverse occurred in both Maths-deficient groups. Webster interpreted his results in terms of inefficient use of memory encoding strategies during verbal information-processing by the two Maths-deficient groups.

If confirmed, Webster's finding that Maths-deficient children perform better on memory-span tasks with visually presented material, than with aurally presented material, reinforces the conclusion from Hitch's [19] finding of a time-based decay of information in STM (see page 287), that children should be encouraged by educators to record on paper all partial results when solving mathematical problems. For such Maths-deficient children in particular such a record would not only remove part of the load on their STM storage (whose capacity appears likely to be less than average), but would not be subject to time-based loss, and would be available as visually-presented material at a later stage in the solution-process.

Most of the studies quoted in this section have been concerned with reading difficulties or with learning disabilities in general, whereas we are concerned with mathematical difficulties. This use of other learning-disabled groups is justified on the grounds outlined in Chapter I; that is, lack of studies of purely mathematically disabled groups, the inclusion of mathematically disabled children in general learning-disabled groups, and Webster's review in [33] showing that many reading-disabled children are also mathematically-disabled. And though such studies do not yield hard facts about Maths-disabled children in particular, they are a rich source of hypotheses, experiments and speculations regarding such children. We must, however, be wary of generalising from one group to another without repeating the experiments and measurements concerned.

From the material in this section, we might suggest that similar experiments and measurements on Maths-disabled children with poor digit-span scores would reveal that control processes such as attention are not involved in their poor memory span, but that non-use of mnemonic strategies may be a contributory factor, and that a structural deficit is indicated.

STM AND BRAIN PATHOLOGY

Defects of short-term memory are very common in many clinical neurologically-defined groups, from the temporary amnesia of patients who have undergone electro-convulsive therapy (ECT) to the chronic amnesia of some brain-damaged patients. Some results relating to such groups and the light they shed on the role of STM in mathematical disabilities will now be presented.

Kapur and Pearson [34] compared 100 brain-damaged and 50 normal adult subjects' self-reports of memory symptoms. They found that complaints of spatial disorientation and temporal disorientation occurred only in the brain-damaged group. Moreover, STM was worse in a group of 14 head-injured subjects, as measured by memory for recent events, spoken messages, and recently-read articles. Objectively they scored an average of 1.4 points below the norm on the WAIS digit-span scale, and below the norm on all components of a battery of memory tests.

Bornstein [35] compared groups of ten adult brain-damaged subjects with unilateral lesions of the right- and left-hemispheres respectively. He found normal WISC digit-spans; however, forward- and backward-digit span scores were not reported separately. He did find differences on the subtests of the Wechsler memory scale; logical memory and associate learning were impaired in the left-lesion group, and visual memory in the right-lesion group. The difference between this investigation and that of Kapur and Pearson, which did find WISC digit-span differences between brain-damaged and normal subjects, may lie in the restriction of damage to a single hemisphere in the Bornstein study (i.e. bilateral damage may cause inferior digit-span performance), or to the type of neurological damage sustained, or to the site of such damage.

Cases of amnesia due to brain damage (e.g. Luria's [36] and Goldstein's [37] investigations of war wounds) and alcohol abuse (Korsakoff's syndrome) give rise to STM difficulties. This is usually manifest in difficulty in learning new material, although material in long-term memory (already learned) is not affected. In these cases there may or may not be difficulties in doing Mathematics. Luria [38] cites the case of a patient who could not remember what he had just read or who he had just seen, but could still do mental arithmetic, while other patients, notably those with frontal lobe lesions could not successively subtract 7 from 100 because they failed to keep track of the successive answers.

Both Korsakoff's syndrome and the loss of STM in some senile patients suggest that biochemical changes in the brain can lead to defects of short-term memory.

The evidence for STM deficits occurring as a result of brain-damage or changes in brain biochemistry does not, of course, warrant the inference that such STM deficits always arise from such causes, especially in apparently normal individuals. But it does suggest that neurological causes are at least possible in such cases; and that interference with mathematical processes is a possible outcome.

We now move on to an investigation of STM memory in children underachieving in Mathematics.

CASE STUDIES

Unlike the other two factors investigated (Laterality and Verbal-Nonverbal differences) we have no large data bank to draw on to test our theories and to provide norms, as memory was not tested in the NCDS. Our observations are therefore gathered from small samples of local children and, although not generalisable beyond them, may provide grounds for some further or more specific hypotheses or suggestions worthy of trial.

The tests used throughout our study were the forward Digit-Span test from the British Ability Scales, and the same test with the subject required to repeat the digits in the reverse order (backward digit span which is not used in the BAS). The standard series and BAS standard presentation rate (two per second) were used throughout.

Two confounding factors in all our memory testing were that individuals' practice and use of strategies were not controlled. These are difficult factors to control without introducing additional conditions which possibly interfere with the span measure, and for which there are no well-known population norms; and also such factors are accounted for in the norms quoted in the test manual. Some subjects volunteered the information that they had practiced some sort of memory-span task (notably the 'Simon' game) when asked about their performances; others demonstrated grouping strategies in their recall of forward digits. This latter is a normal subject difference on this task and probably reflects familiarity with digits and/or intelligence. In view of the evidence that neither of these effects seems to transfer to phonomically dissimilar consontant letters (Chase *et al* [22], Dempster [21]), we should certainly add letter-span measures using such consonants to any future test battery.

Despite such drawbacks, our results do yield some positive results : practice and strategies may increase the measured digit span, but low scores still indicate deficiencies. With some reservations, this argument also applies to differences between forwards- and backwards-span scores. Accordingly, any centile score at or below the 15th, provided at least one ability score was above the 50th centile, and any centile score at or below the 30th, provided both ability scores (Matrices and Similarities) were above the 50th, i.e. average ability but memory in lowest 15%, or well-above average ability but memory in lowest 30%, will be regarded in our data as evidence of a possible memory deficit.

In our initial study of mathematical underachievers, this put two sixth-formers and three 12-year-olds into the memory-deficient group. In our second sample, seven 12-year-olds also fell into this category. Many of the other mathematically underachieving children had lower memory scores (in terms of centile scores for age) than ability scores; this is in line with Webster's [33] finding that average memory-span declined with degree of mathematics deficiency between three groups of children. Where discrepancies between Verbal ability and Nonverbal ability scores occurred, the Digit-Span score was often between these two extremes (in terms of centile scores for age) - particularly in the 'normal' class described in Chapter IX.

More confirmation of the role of poor STM in some mathematical difficulties comes from an analysis of group means of the groups studied in our investigation.

The 'normal' class of 26 children aged 12 to 13 averaged a forward digit raw score of 26, at the 73rd centile. The sixth-formers of our initial sample averaged a raw score of 27½, at about the 60th centile for age. While the 'normal' group comprised average to above-average ability children, so that the high group average memory score is not unexpected, the sixth-formers comprised a well-above-average group, and an even higher group average memory score might be expected. The initial sample of mathematical underachievers excluding the sixth-formers averaged a raw score of 24 at the 60th centile, while the second sample averaged 21¾ at the 32nd centile. Interpretations of these scores is difficult because of differences in intelligence among and within these groups of children, but the second sample mean does seem very low. Table 7.1 gives details of group means, for both memory and for ability measures.

From this table it can be seen that, within the mathematical-disabled groups, some memory scores were very high, and it is clear that in these cases memory is not implicated in the disability. In other cases, memory scores were so low that, taken with the finding that other factors were not strikingly abnormal, memory deficits appear to provide a large factor in explaining the pupil's mathematical difficulties.

Two such cases were presented in some detail in Chapter V. We shall give a recap of our findings described there, and present some transcripts of their performances when "thinking aloud" while trying to do a Mathematics test.

TABLE 7.1

GROUP MEANS OF MEMORY-SPANS AND ABILITY MEASURES

GROUP	MEAN MEMORY		MEAN ABILITY	
	FORWARD SPAN	BACKWARD SPAN	VERBAL ABILITY	NONVERBAL ABILITY
Normal 12 year-olds	26 = 73rd centile (min 22; max 34)	$18\frac{5}{13}$ (min 11; max 25)	$16\frac{5}{13}$ = 82nd centile (min 14; max 20)	$8\frac{2}{13}$ = 54th centile (min 7; max 9)
Sixth-formers Maths. under-achievers	27.4 = 61st centile (min 16; max 33)	$18\frac{7}{8}$ (min 10; max 23)	$19\frac{1}{8}$ = 89th centile (min 18; max 21)	$8\frac{1}{4}$ = 30th centile (min 7; max 10)
Initial sample Maths. under-achievers	24.0 = 60th centile (min 17; max 31)	$15\frac{2}{9}$ (min 10; max 25)	$14\frac{5}{18}$ = 53rd centile (min 11; max 18)	8 = 57th centile (min 4; max 9)
Second sample Maths. under-achievers	$21\frac{3}{4}$ = 32nd centile (min 15; max 28)	$14\frac{1}{14}$ (min 9; max 22)	$15\frac{5}{14}$ = 59th centile (min 10; max 19)	$7\frac{3}{28}$ = 37th centile (min 4; max 9)

TWO CASE STUDIES OF SIXTH-FORM MATHEMATICAL UNDERACHIEVERS

The subjects concerned were both sixth-form pupils, a girl and a boy. Both had failed to obtain pass grades in 'O' level Maths, although they had 6 and 7 'O' level passes respectively in other subjects. On the Digit Span-forwards task from the British Ability Scales the girl was on the 1st percentile for her age; she could repeat only four digits accurately. The boy, who was specialising in Languages, was little better at the 11th percentile. He had a brother, in the year below, who was specialising in Mathematics; on the same Digit Span task this brother scored in the top 10% for his age, suggesting that Mathematics achievement and Digit Span may be intimately related in these two brothers.

Both these sixth-form memory-deficient subjects agreed to do some questions from the NFER test, Basic Maths. Test F-G designed for 13 year-olds. They were asked to "think aloud" while doing the questions and their responses were recorded and later scrutinised. This test should have been easy for pupils who had covered the 'O' level syllabus, and, indeed, neither had any difficulty in understanding the questions and very little trouble in selecting appropriate strategies. Figures 7.6 and 7.7 consist of extracts from the respective transcripts, showing how each subject performed. Interpretations of how mistakes were made are given in parentheses.

FIGURE 7.6

J'S PERFORMANCE ON NFER BASIC MATHS TEST FG

* QUESTION NO.	J'S ACTUAL WORDS	OUR COMMENTS
Q1-4	"Try □ = + . 5 + 2 = 7. No good." "Try x 5 x 10 = No good." "5 ÷ 2" "So □ = - " "5 - 2 x 3 = 6 so □ = - ◇ = x"	Here he had to recall the - sign to do the 5 - 2 operation, hold the result in memory, and produce the operation needed to make the answer equal to 6.
Q5-8	"11 - 3 = 8 and + 16 = 24" "4 ÷ 5 x 10 = 50 ÷ 4"	Here he was recalling the operations ÷ and x while performing the calculation.
Q20-22	"$\frac{1}{2}$. That's 50% and .5" "$\frac{4}{5}$. That's 80%. Not $\frac{5}{10}$. Not .4. Not 40%. .8" "$\frac{3}{10}$ is .3. It's not 3% which is $\frac{3}{100}$".	Then he hesitated and wrote 3%.
Q31	"2 x 2 = 4" "$\frac{1}{2}$ x $\frac{1}{2}$ = $\frac{1}{4}$" "So it's $\frac{1}{10}$"	Here he was trying to keep in mind the 2 sums just done and the algorithm he had worked out to solve the problem.
Q37		He made two attempts to draw the new position. Both were wrong. He worked out how the axes were rotated but seemed to forget this when attempting to rotate the shaded area.
Q38-40	"3 x 3 = 9" "3 = 3 x 3 = 9 and x 3 = 27 and x 3 = 81" "4 x 4 = 12 and $\frac{12}{4}$ = $\frac{6}{2}$ = 3".	He could not remember notation. This was explained to him but appeared to be difficult to remember - the effort of remembering may have caused the error.

Our comments at the time were that we favoured the STM explanations for these errors because : (i) his digit-span score was very low and his performance very variable; (ii) we detected no lapse of attention - eye movements, etc., suggested attention to questions; (iii) he did far more difficult mechanical arithmetic with no hesitation or difficulty; (iv) on being asked to repeat that part of the calculation where the error occurred, he looked disdainful and got it correct.

* See Appendix 7.3 (inside back cover) for details of the questions asked.

FIGURE 7.7

V'S PERFORMANCE ON NFER BASIC MATHS TEST FG

QUESTION NO.	V'S ACTUAL WORDS	OUR COMMENTS
Q5-8	"11 - 3 = 8 and + 16 = 24" "4 ÷ Oh dear" ← "50 ÷4 = 12½" "8 x 5 = 40 ÷ ..." "So x = 10. Oh! Divided not times"	Finger counting. Had to recall meanings of x, ÷ and order rules and remember the numbers concerned. Wrote down 40 x x = 4.
Q9	"13 - 10 = 3" "19 x 3 = 16 and - 3 = 13"	Counted on fingers. Next she appeared to have forgotten the 16 and had to go back. Then she seemed to forget the rule. But finally produced the '7' in the sequence.
Q13	"8 ÷ 15. Does that mean 8 goes into 15?" "I shouldn't have to work these out! ← It's >".	Forgot meaning. Compare with K!
Q37	"So it's just turned round one side"	She drew it correctly at once. But then she started to check co-ordinates, kept forgetting the direction of rotation, got confused and gave up.
Q44-45		For these questions she used a visual strategy. She hesitated and paused and made several wrong trials. She kept forgetting which squares she had already used as equivalent to the second figure.
Q55	"$^{11}/_{12}$"	Forgot what the question asked for?

Our comments at the time were that V tended to check her calculations and did use the rough paper provided. But she seemed to lose her place in the algorithms while performing arithmetical operations, even when doing simply long multiplication. Multiplication tables were much weaker when solving problems than when tested in isolation. Attention to the task appeared to be excellent.

Although the possibility that mistakes were due to inability to sustain attention cannot be ruled out, the subjective view at the time was that attention was maintained throughout each calculation. This would be in line with the finding of Torgesen and Houck [26] that poor readers with low digit-span scores could maintain attention as well as controls.

These two subjects differed from those discussed in Chapters VI and VIII, for although one of them, at least, had quite a large Verbal-Nonverbal difference and the other was cross-lateral, their difficulties in Mathematics, as judged by their performances on the Basic Maths Test F-G seemed to be clearly due to calculation errors, based on memory failure, rather than comprehension or strategy difficulties. However, these two subjects were older and of a higher ability than many of the cases discussed there. Although there is overlap between the groups, we can distinguish a fairly 'pure' sub-group, distinguished by very poor memory span, typified by the two subjects discussed here.

CASE STUDY OF A 9-YEAR-OLD GIRL

This is a study of the only child who fell into the group with low digit-span scores for whom we have any background data at all comparable with that for the NCDS children. It is therefore remarkable that it yielded direct evidence of possible neurological involvement.

The parents of a 9-year-old girl (G) requested that we look at G with them because they were worried about her mathematical performance. (This is in contrast to other children in our study who were referred to us by the schools as underachieving in Mathematics, and for whom the schools could supply no background material).

G was born abroad; pregnancy and birth were both considered normal, as far as the parents are aware. Five days after birth, however, the baby went into convulsions which lasted for 24 hours. Tests revealed no abnormalities, and there were no later episodes. But at 7 years, G caught chickenpox and was very ill, developing encephalitis.

At three years of age, G went to playgroup-cum-nursery school. The family moved back to England when she was five, and she then started full-time at a local infants' school. She made average progress in all subjects except Mathematics, and this worried the parents but not the teachers. (The parents said that neither of them was good at Mathematics and the father in particular had a miserable time at school because he found Mathematics difficult to understand). The parents arranged for G to have extra Maths. tuition outside school and she made some progress, until six months before we saw her, when her tutor could no longer continue. At the parents' request, G was being given remedial lessons in Mathematics, one period per week, with the 'slow learners' at the junior school she was then attending. This had started in the term in which we saw her.

We administered the short forms of the four subtests of the British Ability Scales required to compute IQ scores; these tests were Speed of Information Processing, Matrices, Similarities, and

Forward Digit Span. We also tested her on backward-digit span, letter span, laterality preferences, walking backwards on a straight line, and selected questions from a diagnostic Mathematics test (NFER : Profile of Mathematical Skills Levels 1 & 2).

Her scores were as follows (raw scores) :

Speed	0 (below 27th centile)
Matrices	$^{4}/_{11}$ (approx. 25th centile)
Similarities	$^{10}/_{21}$ (approx. 40th centile)
Digit Span	15 (approx. 8th centile)
Backward digit span	2 digits
Letter span	4 letters
Lateralities	Homolateral R (RH, RE, RF)
Walking backwards	Steady.

The four relevant BAS tests gave her an IQ rating of 84, which we considered a likely underestimate (previous use of these sub-scales by the author had yielded consistent underestimates for younger children). In conversation she was articulate and showed comprehension; parents and teachers were very satisfied with her reading performance and most other areas of school work, and she was quick to grasp what was required of her in the testing sessions.

We used the Speed of Information Processing test to assess her comprehension of the ordinal number system (relative sizes of numbers and place value). We may have over-emphasised accuracy on this test, since she was quite accurate but just too slow to score points. On both the Similarities and Matrices tests we noticed a tendency to perseveration and inflexibility. This was very marked after the test when we asked her to explain her answers to the Matrices problems; having found a method which clearly gave the correct answer to one question, she then applied the same method to all the following (more difficult) problems, whose answers were not so obvious on visual inspection alone.

Her Digit Span, backward digit span and letter-span were all roughly equal (4 items) : a consistency found in some learning-disabled groups (e.g. Torgesen and Houck [26]).

Her performance on the Mathematics questions, when she was asked to 'think aloud' as she did them, showed that where she had overlearned material she could be accurate and confident. She used the rough paper provided to assist memory and produced the following examples :

```
  79      16
 +91      x4
 ---      --
 170      64
 ---      --
  1       2
```

But she then began to make errors, showing that subtraction and, more particularly, division had either not been correctly stored or was not correctly retrieved :

```
                   1
  53     186     2√68
 -35    -127      2
 ---    ----     ---
  22     011      48
 ---    ----      24
                 ---
                  24
                 ---
```

On the other hand, asked what operations were necessary to solve certain easy problems, she had no difficulty in identifying subtraction problems. Also, when cued with a reminder of which number was being subtracted, she was able to do the subtraction sums, showing that the principle had been correctly stored and could be correctly retrieved. Further questions showed that the techniques of long division had not been correctly stored.

A pattern of erratic errors appeared throughout her school work. For example, she could tell the time, knew the number of minutes in one hour, etc. and, in translating times of day from words to numbers she correctly translated :

Ten to three is 2.50

but later she made the following errors :

Five past six is 6.25
Thirty five minutes past four is 7.40
Five past three is 5.15
Fourty minutes to two is 2.40.

These phenomena can be explained, using the Baddeley and Hitch model, in terms of a very limited STM. This would imply a slow rate of learning, so that items in LTM, unless overlearned, would need conscious retrieval. Thus, less familiar processes, such as subtraction, would need more attention from STM than more familiar processes, such as addition. Moreover, once the number of items to be remembered approached four (her memory span), processing capacity would be impaired (Baddeley and Hitch [6]). In the 'times-of-day' problems above one has to remember (i) the hours digit(s); (ii) the minutes digit(s); (iii) 'to' or 'past' the hour; (iv) there are 60 minutes in 1 hour; (v) which digit(s) refer to hours and which to minutes.

In support of our hypothesis of a STM-deficit, G's parents reported that she was unable to run simple errands or carry messages because she forgot what to ask for or what the message was.

Of course there are other possible explanations; G may have a phobia for numbers, she may be emotionally disturbed, she may have a couldn't-care-less attitude. If so, neither we nor her parents have detected evidence of any of these states. Her behaviour appeared normal, she showed no behaviour changes when dealing with different kinds of material, she appeared to devote as much time and attention to our tests as she did to her lace-making (which was very good, and also showed a quick grasp of a quite complicated process), and she was pleased when her efforts were praised.

However, we do not rule out the possibility that deficits other than STM may underlie G's performance, but recommend that some attention be given to this aspect.

LINKS BETWEEN STM AND THE OTHER TWO SIGNIFICANT AREAS OF FUNCTIONING

Table 7.2 gives the test scores, across the whole battery of tests which we administered, of the group of mathematical under-achievers with poor Digit Span (forwards) scores (the group identified earlier in this Chapter).

From this table we see that some cross-laterality (one child was mixed-eyed) is associated with the low memory score in nine of the twelve cases. The two findings, that laterality preferences and learning disabilities appear to be linked, and that poor memory spans and learning disabilities also appear to be linked (Chapters VI and VII), which we have not seen investigated together in the literature, may therefore have some underlying phenomenon in common. The possibility of such links between poor memory, laterality preferences and learning disabilities would be worth further investigation, preferably in large-scale studies.

From Table 7.2 we also see that large V-NV differences occur in many of the poor memory group. However, it is not the centile score differences, but the associated T-score differences that determine the significance or otherwise of these results. Of the eleven children tested, this puts two into the category of 'significant' V-NV differences using our criterion specified in Chapter V. It suggests that in some cases there may be a connection between V-NV discrepancies and low memory span scores. Again, a large-scale study would be required in order to test such a hypothesis.

TABLE 7.2

TEST SCORES OF 'POOR MEMORY' GROUP OF MATHS. UNDERACHIEVERS

SCHOOL	CHILD	AH3 V	AH3 N	AH3 P	AH3 TOTAL	LATERALITY H - F - E	L - R	DIGIT SPAN FORWARD	DIGIT SPAN BACKWARD	MATRICES	SIMILARITIES
A	e	18	8	20	46	R - M - L		30	4^-	65	97
D	a	13	6	18	37	R - R - R	*	8	3^+	70	80
B	c	15	11	22	48	R - R - M	o	21	4	70	68
B	i	o	o	o	o	R - R - R	**	1	3	45	88
(sixth formers)	j	o	o	o	o	R - R - L	o	11	3^+	o	o
A	+m	15	3	18	36	R - M - L	**	10	3	16	65
	q	14	5	15	34	R - R - R	**	23	5	83	80
	+s	10	4	13	27	R - R - L	**	29	4^+	60	78
	++w	11	5	23	39	R - R - L		10	3^+	34	88
	x	8	8	17	33	L - M - R	*	15	4	16	78
F	i	12	8	20	40	R - R - L		6	$3\frac{1}{2}^+$	58	26
	1	16	6	22	44	R - R - L		4	$3\frac{1}{2}$	32	63

\+ = unsteady
++ = very unsteady
walking backwards on a straight line.

o = not tested

Other meanings as in Table 4.2.

A possible connection between Verbal and Nonverbal abilities and STM has been raised elsewhere in the literature by Black [39]. Although it highlighted a different aspect from that mentioned here it is relevant to a study of neurological factors in learning disabilities and warrants some discussion.

FORWARD SPAN AND BACKWARD SPAN CONNECTIONS WITH VERBAL AND NONVERBAL ABILITIES

We have already mentioned that both forward-span and backward-span correlate with intelligence, or ability scores, backward span more highly than forward span (see earlier review of the Memory literature). Differences between forwards and backwards span scores vary from subject to subject but are normally between 0 and 2 digits; forward span is never less than backward span (see for example Black [39]). Black discussed the possibility that large differences between forwards and backwards digit spans (3 or more digits) may be pathological.

He found that in a group of 100 learning disabled children, the number of such cases was larger than expected and that more of them (59% vs. 33%) had positive neurological symptoms on a screening test and neurological examination. He also found that average forward digit-spans of this LD group were very little below those predicted by their average intelligence scores, in support of Torgesen and Houck [26] who also found a LD group with normal digit-span, but contrary to many findings with LD groups.

Measuring Verbal ability by the Peabody Picture Vocabulary Test, and Nonverbal ability by the Bender-Gestalt Test, Black found that in his LD group, forward digit span correlated significantly with Verbal ability (and almost reached significance with Nonverbal ability), while backward digit span correlated significantly with Nonverbal ability.

Black also noted that his LD group contained many subjects with large V-NV discrepancies. Unfortunately, he did not report on the relationship between large discrepancies in V-NV abilities and large differences between forward and backward digit spans; although he was trying to examine the hypotheses that digits-forwards is a left-hemisphere task and thus related to the left-hemispheric Verbal abilities, and that digits-backwards is a right-hemisphere task and thus related to the right-hemisphere Nonverbal abilities. He supported these hypotheses with the significant correlations mentioned in the last paragraph.

Our data, however, suggest that V-NV differences and forwards-backwards span differences are different syndromes.

Firstly, among the sixth-formers of our initial sample, we found V-NV centile-score-differences ranging from -15 to +80, while forwards-backwards digit-span raw score differences ranged from 5 to 11 on the BAS scales (equivalent to 1 to 2 digits).

Large differences in span scores occurred in only one younger member of the initial sample, and he had equal V and NV centile scores.

Those subjects in the initial sample with the largest V-NV centile score differences had raw score span differences of 8 and 9 respectively (1 to 2 digits).

In our initial study we also found that those subjects whose memory spans were much lower than their ability scores, in age-normed centiles, tended to have very small span differences, perhaps reflecting the very low forward-span scores. These were the children who appeared to us to have pathological memory scores.

In our second sample, large V-NV centile-score differences (48 centiles or more) occurred in 10 out of 28 subjects, with forwards-backwards span differences ranging from 0 to 16 raw scores (0 to 3 digits) the latter at the 'pathological' level suggested by Black. Eight of these subjects had V > NV with an average span difference of 7.6 (range 0 to 16) raw scores; two had V < NV with an average span difference of 9.5 (7 and 12) raw scores. Black's hypotheses should surely lead to diminished span differences in the V < NV cases. Again, those subjects whose memory spans were much lower than their ability scores, in terms of centiles for age, tended to have small span differences (range 0 to 8 raw scores).

Finally, we compared the results from our two samples of mathematical underachievers with a 'normal' class of average-to-good comprehensive school children of the same ages. (Actually this group did contain two mathematical underachievers - see Chapter IX). We found large V-NV differences of 48 centiles or more in 6 of the 26 'normal' children, all had V > NV. The forward-backward digit span differences ranged from 5 to 11 raw scores (average 8.5) - equivalent to 1 to 2 digits. We also found 10 subjects whose memory score centiles were well below their ability test centile scores; their span differences ranged from 0 to 10 (average 4.9) raw scores, and of these six were less than 5 points (1 digit). However, none of these memory span centiles, or those of the other children in the class, were in the lowest third of population scores (BAS norms), and cannot therefore be considered abnormal by our criteria.

Black was trying to link forward- and backward-digit span measures to the workings of the left- and right-hemispheres respectively. Then unilateral brain impairment might be expected to affect one span measure but not the other; and abnormal span scores might thus be indicative of unilateral brain damage. Insofar as unilateral brain impairment might also be expected to produce V-NV discrepancies, our results do not support Black.

Table 7.3 shows the correlations between measures of Verbal ability (a left-hemisphere task), Nonverbal ability (a mainly right-hemisphere task), digit-span forwards and digit-span backwards for the various groups we investigated, together with Black's results. In all groups except our sixth-form pupils, there is a clear positive relationship between Nonverbal scores and digit-span backwards, but no other consistent relationships. But all these groups, with the exception of the 'normal' 12-year-olds, were learning-disabled and the widely different patterns may reflect the varying proportions of different disabilities within each. A multivariate analysis procedure is really needed to clarify the inter-relationships.

TABLE 7.3

CORRELATIONS OF ABILITY TEST SCORES WITH DIGIT SPAN SCORES

	STUDY GROUP	N	TEST	NV	DF	DB
<Mathematical Underachievers>	Sixth formers	8	V	-0.37	0.02	-0.19
			NV		-0.29	-0.39
			DF			0.92
	Initial Sample 12 year-olds	18	V	0.61	0.14	0.41
			NV		0.29	0.28
			DF			0.62
	Second sample 12 year-olds	28	V	0.04	0.06	-0.08
			NV		0.28	0.48
			DF			0.20
	'Normal' class 12 year-olds	26	V	0.35	0.15	0.31
			NV		0.09	0.45
			DF			0.35
	Black's LD study		V		0.38	0.14
			NV		0.24	0.36

SUMMARY OF CHAPTER

We have produced evidence from the literature and from our case studies to show that in some cases learning disabilities and mathematical underachievement occur in conjunction with poor STM, in particular with low scores on the (forward) Digit Span measure.

We have further shown, from some of our case studies, how the hypothesised STM deficit can account for the mathematical errors observed in some of our subjects' attempts at mathematical problems.

In support of a neurological basis for the hypothesised memory deficits, we have shown how such deficits are observed in a range of acquired disorders in clinical groups. And we have presented a case study of a girl with a hypothesised memory deficit whose history contains a significant 'neurological' event.

Looking at connections between our three 'significant areas of functioning', we have shown that our case studies support a connection between STM deficits and laterality preferences and between STM deficits and V-NV discrepancies.

It is clear from the work of Torgesen and Houck [26] and our own case studies that not all learning-disabled children have memory-span deficiencies, so that memory-span deficiencies are thought to be neither a necessary accompaniment to learning disabilities, nor a cause of such disabilities in many cases. We have not been able to find any unequivocal evidence relating to the question : do memory-span deficiencies occur only in conjunction with learning disabilities? Certainly among our 'normal' 12 year olds, no child fell in the bottom third of age-normed Digit Span scores.

Appendices 7.1 and 7.2 contain, respectively, some thoughts on remediation and teaching raised by the research described in this Chapter, and some questions arising out of this research that we should like to see tackled in future.

APPENDIX 7.1

REMEDIATION AND TEACHING

There do seem to be cases of mathematical underachievement in which the chief abnormal psychometric measurement is a very low memory span. Our case studies appear to show how such a low memory span could be the major cause of this underachievement in some cases. The two detailed studies of sixth-formers doing Mathematics revealed no difficulties in understanding the questions, or in finding the correct strategies to solve them, but did reveal memory failures. Moreover, these difficulties appeared to be peculiar to short-term memory. Long term memory appeared to be normal, in that these pupils were doing well in Languages (where long-term memory is constantly employed). Mathematics facts, such as tables, could also be retrieved accurately from long-term memory, provided there was no concurrent load in STM.

There are essentially two ways in which we might try to tackle the problem of remediation in such cases. One is to try to improve STM, the second is to find strategies for coping with a deficient STM.

To take the latter first, it is clear from Hitch's [19] work that even with an unimpaired STM, accuracy in problem solving (mental arithmetic) is improved if partial results are written down as soon as they are obtained. In this way, the blank page acts as an extra memory store, effectively increasing the capacity of STM.

The use of the written record need not be confined to partial results in mental arithmetic; whole strategies could be recorded before computation began, and each stage crossed off as it was completed, thus making repetition or omission of a stage less likely. We have already noted (p.19) that Webster's [33] finding that Mathematics deficient pupils remembered better when items were presented visually reinforces this suggestion. Moreover, from a school child's point of view, writing down a strategy in this way would foster a real 'thinking' approach to the subject - and, in terms of examination performance, it may also earn marks for method, even if accuracy failed.

It was quite striking that in the school samples none of the "memory deficient" children, as defined in this chapter, used the paper we provided for rough working.

As far as improving STM is concerned, the literature provided conflicting opinions. Chase et al [22] quote their experiment in which a subject with normal digit span was practiced on the digit-span task over a whole year (about 200 hours altogether), and increased his digit span, by means of a mnemonic strategy, to over 50 digits. But, on being tested with consonant letters, his span dropped back to 6 (i.e. normal). Similarly, Torgesen and Houck's [26] experimenter-imposed grouping of digits increased both poor and normal memory spans by a similar amount, but the effect was not transferred on a return to normal presentation. These experiments suggest that training in particular strategies in memory-span tasks will be of little help.

On the other hand, if Dempster's [15] theory, that item recognition speed is an important factor in memory span, has any basis, then increasing familiarity with the material should increase memory span. Thus increased exposure time to numbers, algorithms, strategies, and problem types should lead to improved STM for storing these items, and hence to improved mathematical performance. If this were the case, there would be hope that, even if given no remedial programme at school, there would be improvement in adulthood, purely on the basis of exposure to such material. However, there is no evidence that subjects with low spans have been less exposed to such material in the past relative to 'normal' contemporaries (indeed, the uniformity of schooling would suggest similar exposure across all subjects). This suggests that longer exposure times would be necessary for subjects with low memory spans to reach the same degree of familiarity with the material as normals; in the same way that they take longer to reach the criterion of perfect recall on a paired-associate learning task.

Against this conclusion from Dempster's theory, Dempster himself quotes evidence that whatever underlies speed is determined largely by biological factors, and is largely unmodifiable. First, Case [40] found that the age at which counting speed becomes asymptotic is constant across vastly different environments in which counting experiences are supposedly different. Secondly, Kurland [41] trained 6 year olds on counting speed for 3 months, with hundreds of trials per day, with only very small gains - much less than the experiential theory would predict.

Our own experience with the case study children also suggests that the 'poor memory' group are as familiar with the material as mathematical achievers. We have already noted that mathematics facts appeared well-known and that understanding of the problems, recognition of problem types, and strategies for solving them, were as good as among achievers. But these children did appear to have a very small STM store which was badly affected by concurrent prolem-solving.

On the whole, the evidence seems to suggest that strategies for dealing with a deficient STM may be more realistic than trying to improve STM capacity by practice on either material types or strategies. But the evidence is in no way conclusive, and it is clearly an area worth further investigation.

APPENDIX 7.2

FUTURE RESEARCH

Before presenting a list of the questions we should like to see tackled in future research projects, along with those already mentioned in the text of this chapter, we shall briefly outline some of the limitations of our present study. We shall attempt to justify the use of our results, in spite of these limitations, as a basis for addressing the question we started from: Does dyscalculia exist? and for providing questions for future research.

Firstly, testing was done at only one point in time. Ideally, all measures should be repeated. However, in the case of memory measures to identify deficits, both the reliability of Digit-Span measures (WISC and BAS manuals) and the experiments of Torgesen and Houck [26] on repeated measures suggest that single measures are probably sufficient to identify low-scoring subjects.

Secondly, only one type of material was used. A more accurate diagnosis (very low span vs. aversion to digits, for example) might be obtained by using contrasting materials. This could also lead to an evaluation of the use of strategies if phonetically dissimilar consonant letters were used, as well as digits. Digit Span is the most superior single test, however, since norms are available, individual differences are large enough on the WISC and BAS scales for score distributions to be distinguished, and the material should be equally familiar to each cohort of subjects.

In order to test the effect of experimenter on the results, either a second experimenter should be used and the results of the two experimenters compared; or a large sample of 'normal' children should be tested by the same examiner, and the results compared with the norms provided with the tests used. The 'normal' group used for comparison in this chapter was not ideal for this purpose, in that it consisted of too few subjects, all in a restricted ability range. In practice, since the BAS manual gives precise instructions for administration of the Digit Span test (which we complied with, to the letter), and since the Digit Span task is particularly simple, experimenter effect was probably minimal.

In any future research in this area, we recommend that a variety of different materials are used to assess memory span, and that at a minimum forward- and backward- digit spans and phonemically-dissimilar consonant letter spans are measured.

The following is a list of some of the questions which we should like to see tackled.

1. Are all <u>very</u> low memory-span children also underachieving in Mathematics? (If not, does achievement depend on IQ level? i.e. on the discrepancy between memory-span and IQ centiles). (See page 49).

2. Do any <u>very</u> low memory-span children make use of rough paper when doing Mathematics, in order to aid memory? Is such use of

rough paper correlated with Mathematics achievement? (See Appendix 7.1).

3. At what level does memory-span cease to be significant in Mathematical achievement and under-achievement? (See page 49).

4. Among subjects with <u>very</u> low memory spans, is time required to learn lists of items, or paired associates, to perfect recall, related to memory-span, or to IQ, or to forwards-backwards span differences? (See Appendix 7.1).

5. Are memory-span forwards and memory-span backwards correlated more or less significantly in very low memory-span subjects than in normals? (See page 47).

6. Is memory-span forwards related to knowledge of Mathematics facts and algorithms? (See page 45 and Appendix 7.1).

7. Is memory-span backwards related to knowledge of the use of strategies? or to order errors? or to knowledge of left and right? (See pages 44-47).

8. Are children whose digit-span test performances show great variability (e.g. get 4 digits wrong but go on to get 6 digits correct) different from those whose performances show consistency? If so, in what way? (SeeChapter V page 11).

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CHAPTER VIII

VERBAL-NONVERBAL DIFFERENCES

A survey of the literature deals in particular with various theories of how large Verbal-Nonverbal ability differences arise. An analysis of the NCDS data is made to reveal significant differences between an experimental group having large Verbal-Nonverbal differences and the population. Case study data is then considered in an attempt to relate mathematics performance to directional differences in Verbal and Nonverbal abilities.

The third area identified in the earlier analysis of our case-study data as being related to mathematical underachievement in our samples, was large differences between Verbal and Non-verbal abilities.

In this chapter we investigate this area using the NCDS data and our own case studies, in conjunction with the literature on this area. We begin by considering the literature dealing with the origins of large differences between Verbal and Non-verbal abilities.

THE ORIGINS OF LARGE VERBAL-NONVERBAL DIFFERENCES

A search of the literature revealed opinions varying widely on the origins, importance, and consequences of large Verbal-Non-verbal differences. At one extreme there was the view that large Verbal-Non-verbal differences are merely the ends of a natural continuum and have no other meaning (diagnostic value) or necessary consequences, educationally or socially. At the other extreme was the view that such differences arise from neurological malfunction or brain-damage (sustained before, during or after, birth), are diagnostic of such brain malfunction and of the hemisphere involved, and (depending on severity, age of occurrence, and compensating mechanisms employed) lead to some degree of under-performance on a range of intellectual tasks. (See e.g. Berk [1].)

In addition to these, a study of the theoretical literature revealed four suggested causes of large Verbal-Nonverbal differences.

(i) Errors of Measurement : It is clear that the variation can be attributable to marking and coding errors together with errors arising during the tests of ability themselves, such as variations in physical state and the role of guesswork. One could argue that the latter types would be minimised by alternating Verbal and Nonverbal items in a single test instrument, as in the NCDS ; but, on the other hand, in such a test, a preference for one type of item might be exaggerated into a large difference score by a child attempting all the questions of one type first. (It would have been of great interest in our study of the NCDS data if we could have looked at the patterns of responses and non-responses and of errors made by children with large Verbal-Nonverbal differences on this test, but these data were not available.)

Accepting that some error variation certainly exists, it would be a negative stance to ignore the possibility that the variation is more validly attributable to real differences. The theory is testable on the basis that errors of measurement should be randomly distributed throughout the population. Such errors (and hence large Verbal-Non-verbal differences) should have no systematic correlates.

(ii) Natural Phenomena : Depending on one's position with regard to the major theoretical issue of the nature of mental abilities, large Verbal-Nonverbal differences may be regarded as purely natural phenomena. The extent to which this is tenable depends on at least three aspects of the issue : the relative independence of different abilities, the nature-nurture controversy, and the development of abilities.

If different abilities are largely independent, we should expect that sizeable Verbal-Nonverbal differences would be relatively common ; but if they contain a substantial common factor (i.e. of general ability), then large differences should be rare, and possible pathological.

If nurture is more important than nature in shaping abilities, we should expect to find environmental factors correlated with abilities and hence with large Verbal-Nonverbal differences ; in particular, the literature associated with this view would predict class differences such that high Nonverbal, low Verbal scores would occur in the lower social classes with a non-verbal pattern of social activity, while differences in the opposite direction would be fewer in number and more prevalent in the higher social classes. Insofar as they share a common environment, similar Verbal-Nonverbal differences may be expected to occur within families. The 'nature' view also predicts that large Verbal-Nonverbal differences when they occur may be expected to be found within families, since abilities will resemble those of parents and siblings, but also that large differences may occur randomly due to genetic defects.

Whatever the final distribution of abilities in the adult, it could be that different abilities develop at different times and speeds. In this case we might expect large differences to be relatively common during development years. However, we might also then expect one kind of ability to be generally ahead, i.e. that large differences would occur in one direction only.

(iii) Emotional and Psychiatric Disorders : Although there is still controversy about ability patterns found in various emotionally disordered and psychiatric groups, there is some evidence that differences between Verbal and Nonverbal abilities may be typical of some disorders. For example, Matarazzo [2] quoted mean scores on Wechsler Verbal and Performance test batteries of twentynine different groups of sociopaths ; in each group PIQ was higher than VIQ. Other studies, using different populations, have found differences in the opposite direction. Thus, Todd et al. [3] in their study of 78 psychiatric patients found higher mean Verbal scores.

On this basis, we should expect to find large differences in ability scores associated with abnormal scores on emotional and behavioural indices ; and this can be tested in a study such as the NCDS.

(iv) Neurological Malfunction and Brain Damage : A great deal of literature suggests that some types of learning-disabled children exhibit large discrepancies between Verbal and Nonverbal scores on ability tests. Those usually reported are large Non-verbal, low Verbal scores for reading-disabled children while the reverse pattern has been reported for children showing Gerstmann syndrom signs. Thus, Warrington [4] found a high incidence of NV greater than V scores among 76 specific reading-disabled children. This was confirmed later in a retrospective study of 121 children with specific reading and/or spelling retardation and reported by Nelson and Warrington [5]. Moreover, in this latter study, it was shown that the size of discrepancy was associated with the degree of reading retardation (mean difference 14 points on the WISC) but not with spelling retardation (mean difference 0 points on the WISC). Benson and Geschwind [6] reported on two children exhibiting a developmental Gerstmann syndrome whose Verbal abilities exceeded Nonverbal abilities, by 30 points in one case, on the WISC, and quoted 7 more cases investigated by Kinsbourne and Warrington [7].

To the extent that the mental performances of children with certain types of learning difficulty resemble those of brain-damaged subjects, particularly in L-D cases with 'soft' neurological signs such as poor coordination, neurological malfunction is thought to underlie some of these learning-difficulties ; large V-NV differences are often another point of resemblance (see e.g. [1]).

However, neurological impairment does not necessarily lead to large V-NV differences ; for example, some split-brain and lobectomy patients showed no discrepancy (Taylor [8]). This would be expected if side of damage were related to direction of V-NV difference, since damage to both hemispheres could then lead to deficits in both V and NV ; and hence small differences. It is important to recognise that not all learning-disabled children in the studies quoted above had large discrepancy scores, but there are enough positive findings to suggest that certain subgroups appear to have V-NV differences linked to neurological malfunction.

Todd, et al. [3] point out that a discrepancy between Verbal and Performance (Nonverbal) scores on the WISC has been used in clinical practice as an indicator of both brain-damage and lateralization of that damage. They compared discrepancy scores on the WAIS for five adult clinical groups : 78 psychiatric non-brain-damaged, 68 left-brain-damaged, 46 right-brain-damaged, 69 diffuse-brain-damaged, and 74 non-specific brain-damaged. Average discrepancy scores were significant for all five groups, each with depressed Nonverbal scores (in support of Wechsler's claim that any type of organic damage causes impaired Performance scores). The size of the discrepancy in their study did not vary with type (acute/chronic), or side of brain damage (left, right, diffuse), or sex, but did vary with IQ level, being larger for a FSIQ above 110.

The finding of John et al. [9] that groups of learning-disabled children, divided according to whether the disability was in reading only, arithmetic only or in both, exhibited both differential V-NV differences (actually VIQ-PIQ differences on the WISC), having V<NV, V>NV, V≃NV respectively, and abnormal brain-scan recordings, in the left-hemisphere, the right hemisphere, and left-hemisphere different frequency, respectively, does tend to support the link between V-NV differences and neurological abnormalities, as well as the hemisphere links with the directional differences.

If discrepancies are due to neurological malfunction we should therefore expect them :

(i) to occur in either Direction (Taylor [8])

(ii) to be associated with underachievement (e.g. Johns et al.)

(iii) to be associated with factors associated with cases of known neurological malfunction (i.e. brain-damage).

We have briefly described four possible mechanisms which could give rise to large V-NV differences and derived some expected correlates of each.

Bearing in mind the 'natural' or 'error' explanations, the findings related to learning disabilities suggest that it is worth pursuing the connections between mathematical underachievement and large V-NV differences in the NCDS data to consider in more detail any positive relationships between V-NV differences and other factors in mathematically underachieving children.

Before looking specifically at mathematical underachievement it is worth testing the three predictions ((i) to (iii)) above for a general group of children with very large V-NV differences ; positive findings would support a neurological explanation.

In the next section we shall describe the correlates of large V-NV differences which we found in our analysis of the NCDS data.

THE NCDS DATA

PREVALENCE OF LARGE V-NV DIFFERENCES

Considering, first of all, the whole NCDS population, the distributions of raw scores on the Verbal and Nonverbal tests had some deviation from normal (especially the Verbal test) and with small floor and ceiling effects, were not directly comparable in their raw states. The scores were therefore 'standardized' by converting into percentiles, and discrepancies used and discussed are in terms of percentile differences. The distribution of these differences is shown in Table 8.1 and in Figure 8.1.

TABLE 8.1

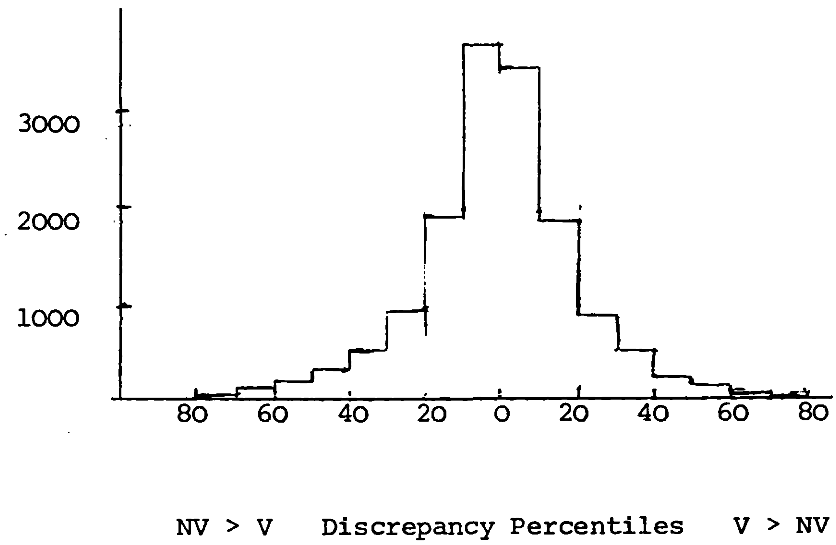
DISTRIBUTION OF V-NV DIFFERENCES IN TEST SCORES

Percentile score difference greater than	10	20	30	40	50	60	70	80
Percentage of population affected	51	24	10.5	4.06	1.46	0.44	0.12	0.01

From the examples given in Chapter II, we see that the Verbal and Nonverbal items, on which these score differences were based, have much in common. They are both based on reasoning by analogy : from the relationships between four items in one configuration one has to deduce the missing item in a similar configuration based on the same

FIGURE 8.1

DISTRIBUTION OF V-NV DIFFERENCES IN TEST SCORES



relationships. They are both laid out in a similar spatial configuration. Thus, unlike the usual Verbal and Nonverbal tests (e.g. the VIQ, PIQ scales of the Wechsler tests), neither the layout of the material, nor the method of solution should affect the V-NV differences. These must be solely due to the material itself (words v. shapes) and the ease of finding relationships between items within the same type of material. The commonalities between the V and NV test items, not surprisingly, give rise to the very large number of very small differences, but it is all the more surprising therefore to find such large differences at the extremes. Although the 'error' theory would imply a normal distribution of differences, it would not predict differences of the scale shown in Figure 8.1. This point is returned to shortly.

The factors giving rise to V-NV differences here (i.e. words or shapes, and the ease of finding relationships between items within the same type of material) are also present in the V-NV tests used in our case studies. We should therefore expect some subgroups of the children identified by large V-NV differences in the NCDS to be similar to our case studies, although there may be some case-study children identified by other factors (such as oral versus written presentation) which do not apply to the NCDS sample.

In order to look more closely at large V-NV differences using the NCDS data, we should have liked to look at very large V-NV differences in our SMU group. Unfortunately only one child from the SMU group had a really large V-NV difference ; she is described in Appendix 8.2 (case 50). It is very likely that the other SMU group children with moderately large V-NV differences would be comparable with our case study children with large discrepancies between Similarities and Matrices scores, since the nature of the NCDS ability tests would tend to obscure some aspects of such differences. However, because the essential characteristics of children with very large V-NV differences would be expected to show up most clearly in a very extreme group, we decided instead to choose a group of children with very large discrepancies. The identification of such a group (the experimental or E-group) is now described.

The Experimental Group

Berk [1] analysed the reliability, abnormality and validity of Verbal-Performance discrepancy scores on the WISC-R in relation to clinical decision-making regarding learning disabilities. He quoted Wechsler's computation that a reliable (i.e. statistically significant) discrepancy score is 12 points (p = 0.05) or 15 points (p = 0.01), and also reported Kaufmann's finding that, in a standardization sample of 2,200, 4% of children had discrepancies of 25 points or more - an abnormal statistical discrepancy. He defined a valid discrepancy from a psychological point of view as one that would differentiate between a child who is learning-disabled and one who is not, but concluded that as yet studies of validity of discrepancy scores are inconclusive.

Now Wechsler's scales all have means of 100 and S.D.'s of 15, so that a difference of 25 points on his scales (obtained by 4% of Kaufmann's standardization sample) is roughly equivalent to a difference of 60 centiles. In our data the extreme 4% had discrepancies of 40 centiles or more ; our tests were more crude and narrow that the tests making up the batteries used in the Wechsler scales, and so discriminations may have been less reliable. In the following therefore, in order to reduce the chances of type I error i.e. inclusion of non-valid cases, and to increase the chances that our analysis would yield real correlates, our sample of children rated as having large discrepancy scores (the E-group) was chosen to consist of those children whose V and NV scores differed by 60 centiles or more (0.44% of our total population).

The E-group so defined comprised 56 subjects, 37 boys and 19 girls. Discrepancy directions within this group are shown in table 8.2.

TABLE 8.2

DISTRIBUTION OF DISCREPANCIES IN THE E-GROUP

	V > NV	NV > V	Total
Boys	6	31	37
Girls	11	8	19
Totals	17	39	56

From table 8.2 we see that neither the boy/girl ratio nor the V>NV, NV>V proportions are random as would be expected on the basis of the 'error' hypothesis, and we therefore reject the 'error' hypothesis as an explanation of the occurrence of large V-NV differences in the NCDS data.

There was a tendency for girls to have larger Verbal scores, and boys larger Nonverbal scores, significantly in the E-group, very weakly in the population. The overall total of twice as many boys as girls clearly arises largely as a result of the number of boys with high NV-low V scores. This finding confirms many studies which have found a similar ratio between boys and girls in reading-retarded (i.e. under-achieving) groups, where the subjects also had low scores on V-related tasks (e.g. reading), but normal abilities (e.g. Rutter and Yule [11]).

Correlates of Large V-NV Differences

We now look at the correlates of large V-NV differences in order to test our predictions (p.339) derived from the 'neurological' hypothesis of the origins of very large V-NV differences that such correlates would include underachievement and 'neurological' factors. We have already seen that the prediction of large differences in both directions (V>NV and NV>V) has been fulfilled.

The 56 E-group children were compared with the total population on a total of 317 variables, altogether representing the four ages (birth, 7, 11, 16) at which NCDS data was collected. (The E-group being identified by scores on tests at age 11). For the purpose of reporting results, these variables have been divided into seven categories, some variables appearing in more than one category. Comparisons were generally made using Chi-squared tests, but some t-tests were used for the interval-scaled data. A 5% level of significance was used generally, although most variables which were significant also reached the 1% level of significance.

Because of the large number of variables tested, some significant findings are expected to arise as statistical artefacts, and this should be borne in mind when assessing the results.

By defining the E-group as those children whose VA and NVA scores differed by more than 60 centiles, we thereby excluded children with very high or very low total ability scores from the E-group. In order to establish whether this could account for significant differences between the E-group and the NCDS population (T), the E-group was also compared with the large subgroup comprising those children whose total ability scores fell in the same middle-ability band (MA) - i.e. total ability scores between the 30th and 60th centiles. On the whole, this produced the same significant variables and the same trends as the comparison with the total NCDS population, on which the following report is based. Where variables reached significance with one of T and MA but not with the other, this will be indicated.

Summaries for each of the seven categories of variable are given here :

(i) Social and Family Variables : The most significant variable in this category was social class, the E group differing significantly from T because of the large proportion of its members in the 'no male head' category.

Significantly more E-group mothers were thought by teachers to take a strong interest in their child's education at the age of 7, and more wanted their child to stay on at school. By the age of 11 more E-group families had had contact with special education departments and 'emotional' (but not 'behavioural') clinics. By 16 years, significantly more E-group parents were dissatisfied with their child's present school on more than one count, and the children's scores on the Academic Motivation Scale were significantly clustered in the middle range.

(ii) School Variables : There was a significant difference at all ages between the children of the E-group and those of T on type of school attended and need for help with backwardness : proportionally more E-group children were attending special schools, and more were thought by teachers to need help or special schools. In secondary schools, at the age of 16, significantly more of the E-group were attending all-girls schools.

Absences from school tended to be fewer but for longer periods in the E-group, and at all ages teachers considered that they were 'condoned by parents' and 'for trivial reasons'. Moderate truancy was significantly more prevalent in the E-group at age 16.

(iii) Physical and Sensory : At all ages doctors assessed sight and hearing of members of the E-group as giving no serious problems, although there was a tendency for minor problems. By the age of 16, one member of the E-group was considered to have a mild general motor handicap.

At all ages more E-group children were described as 'tall for age' or as 'very small', significantly so at 11 and 16 years. There were, however, fewer extremes of weight and none were 'very fat' at any age.

(iv) Emotional and Behavioural Variables : At 7 years none of the E-group children had attended a child guidance clinic, there was just one case of 'slight' emotional maladjustment. Both teachers and mothers rated them as having settled down at school slightly better than average. By 11 years significantly more E-group children had had psychological or psychiatric opinions or treatment, and by 16 years, significantly more had developed emotional or behavioural problems.

Teachers' ratings of behaviour on a wide range of syndromes (the BSAG) was not significantly different in total for the E-group at 7 years, but by 11 years the tendency for the E-group to obtain fewer high or low scores had reached significance. At all ages the E-group children were described as more 'anxious', 'moody', 'restless' 'inattentive', depressed and 'an outsider'.

(v) Pregnancy and Birth Variables : Significant variables in this category included bleeding in pregnancy (there was more accidental antepartum haemorrhage (APH) and more bleeding pre-20 weeks in the E-group), method of delivery (more assisted breech and more internal version in the E-group) and the sex of the baby (there were significantly more boys in the E-group).

Compared with MA there were significantly more premature births (34-38 weeks gestation) in the E-group, and more mothers were very short or very tall.

More E-group mothers were aged 35 to 40, more babies were fourth in birth order, more mothers had experienced raised blood pressure or proteinuria (pure toxaemia or proteinuria CSU) during pregnancy.

Perhaps significantly in view of the hypothesis of Kawi and Pasamanick discussed in chapter II, the mortality ratios for all of these pregnancy and birth variables in the Perinatal Mortality Survey, were greater than unity, reaching 10 and 11 in two cases.

(vi) Coordination and 'Neurological' Variables : Although not reaching significance, twice as many E-group children were rated by their teachers at the age of 7 as 'certainly' having poor control of hands, poor physical coordination, being clumsy, and difficult to understand because of poor speech. By 11 years, the three former variables were normal, but the latter variable had reached significance. By 16 years, the E-group were significantly more unsteady hopping on either foot, and significantly poorer catching a ball with either hand. At all ages the E-group were more 'restless'.

There were nearly twice as many fits or convulsions between one and seven years among the E-group but fewer headaches or migraine were reported ; by 11 years there were again more minor convulsions, faints and 'turns', and also more recurrent headaches. The latter variable reached significance at 16 years.

At age 7, the E-group contained slightly more left-handers and fewer mixed-handers, significantly more mixed footed, and significantly more mixed-eyed children. By 11, more of the E-group were right-handed, more were right-footed, and more were left-eyed ; 41% of the E-group (compared with 33% of T and less than 30% of MA) were cross-lateral (hand-eye). But at 16 years, more of the E-group thought their left hands were best for writing.

(vii) Ability and Achievement : We have already noted that at all the ages surveyed, significantly more E-group children received or were thought to need, help with educational or mental backwardness; and that more had poor speech and speech defects. Twice as many had not started talking by two years, according to mothers.

Teachers' ratings of achievement, and achievement test results were significantly below those for T at all ages (on average). In particular, by 16 years significantly more of the E-group were rated by teachers as not being able to read well enough for everyday, and significantly more as being unable to do everyday calculations.

At 11 years, the E-group average for the Verbal ability test was significantly lower than that for T, but the average for Nonverbal ability was significantly higher, the overall ability scores did not differ significantly.

Summary of E-Group Relative to Population

The overall impression from our comparison of the E-group with T and with MA on 317 variables, is that of a group of children who had experienced adverse factors in pregnancy or at birth, who were more prone to fits and convulsions, whose coordination was poor throughout the school years (non-significance at 11 years was probably due to the confounding effects of pubertal development at that age), whose behaviour and emotional development deteriorated after the age of 7, and who underachieved throughout the school years.

All of these children were of above-average ability, either in Verbal or in Non-verbal ability (at or above the 60th centile), by definition. Yet at the age of 16 some of them could not read well enough for everyday and others could not do everyday calculations.

Thus neurological indicators and underachievement come together quite strikingly in the E-group, fulfilling the other two predictions of the 'neurological' hypothesis of large V-NV origins.

Underachievement and V-NV Differences

We now look at the connections between large V-NV differences and underachievement in the NCDS ; firstly with regard to underachievement in general (Maths or Reading Comprehension or both) and then more specifically at Mathematics underachievement.

1. In the NCDS Population Generally : It was instructive to break down ability and achievement data for the total population by V-NV discrepancy score. This is shown in Table 8.3.

Table 8.3 shows in general, as we should expect, that for both Reading Comprehension and Mathematics the higher the child's total ability, the higher the performance score. The table also supports

TABLE 8.3

MEAN ABILITY AND ACHIEVEMENT SCORES BROKEN DOWN BY V-NV DISCREPANCIES

	V > NV PERCENTILE DIFFERENCES NV > V																
MEAN SCORES	70 to 80	60 to 70	50 to 60	40 to 50	30 to 40	20 to 30	10 to 20	0 to 10	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80	80 to 90
V	34	32.7	30.4	29.7	27.5	26.2	24.3	22.7	22.3	20	18	16	14.3	12.9	9.6	7.4	2.0
NV	12.5	14.2	15.4	16.3	16.7	18	18.6	19.9	22.5	23	23.6	24.3	25.5	26.7	27.1	27.9	29
TA	46.5	46.9	44.9	46	44.2	44.2	42.9	42.6	44.8	42.9	41.5	40.4	39.8	39.6	36.7	35.3	31
RC	15.5	17.5	18.6	18.3	17.6	17.4	16.7	16.2	16.4	15.3	14.5	13.4	12	11.3	9.8	5.7	2
M	12.5	18.9	19.1	19	17.1	17.2	16.9	17	18	16.2	14.8	13.4	11.5	10.9	8.5	8.7	8

the well-known hypothesis that, in this relationship, Verbal ability is more important than Nonverbal ability, in general. However, the table also gives support to our finding of underachievement among the children with very large V-NV differences, since achievement declines at both ends of the distribution of such differences. Table 8.3 also shows, as we should expect, that Reading Comprehension scores are more closely tied to Verbal ability scores, but for the Mathematics scores, the two separate maxima across the V-NV differences suggest that Nonverbal ability is also a significant influence.

There is also some support for a general ability factor, which runs through all ability measures and also through achievement measures. This is shown by the high correlations between the variables used in Table 8.3 ; these correlations are shown in Table 8.4.

TABLE 8.4

CORRELATIONS BETWEEN ABILITY AND ACHIEVEMENT TEST SCORES

	V	NV	TA	RC	M
V	1.0	0.81	0.96	0.75	0.79
NV		1.0	0.94	0.65	0.74
TA			1.0	0.74	0.81
RC				1.0	0.75

(Abbreviations are shown on p. iv)

The high correlation between V and NV abilities and the very peaked distribution of V-NV differences suggest that these abilities are not totally independent, in fact that they have a substantial 'general ability factor' in common. This would suggest that very large V-NV discrepancies may be pathological rather than natural. These correlations also imply that we should expect higher achievement scores from children of higher ability.

But perhaps these interpretations of the data are too naive. Children at the ends of the ability range were precluded from the E-group by definition, and the pattern of achievement scores shown in Table 8.3 may be an artefact of such constraints. A comparison was therefore made of the achievement scores of children who had the same total ability scores, but with varying discrepancies between V and NV scores. For this comparison an arbitrary sample of Total Ability scores was selected to cover the range of such scores found in the population. The results of this comparison are shown in Table 8.5 ; and as we can see confirm the pattern found above i.e. higher attainment scores (M and RC) with higher Verbal ability, but under-achievement at both extremes of V-NV differences, for a given Total Ability score.

From this table, it appears that, for a given total ability, achievement scores (particularly RC) are enhanced by larger Verbal ability components, as we should expect from previous research on academic achievement, but that this relationship breaks down for very large discrepancies in V, NV components at all levels of total ability.

TABLE 8.5

Achievement Scores for Selected Abilities Broken Down by V-NV Differences

		V > NV					Percentile Differences					NV > V						
		70to 80	60to 70	50to 60	40to 50	30to 40	20to 30	10to 20	0 to 10	0 to 10	10to 20	20to 30	30to 40	40to 50	50to 60	60to 70	70to 80	80to 90
TA=15	RC							8.2	8.4	6.9	6.6	0.0						
	M							1.8	3.8	2.4	2.3	0.0						
	(N)							(9)	(64)	(18)	(9)	(1)						
TA=25	RC					10.5	13.1	11.1	11.2	9.9	9.4	8.3	11.2	5.8		9.0		
	M					5.8	7.3	6.3	6.8	7.4	6.3	4.7	8.8	3.3		6.0		
	(N)					(6)	(13)	(29)	(49)	(25)	(40)	(7)	(6)	(4)		(1)		
TA=30	RC			12.0	13.0	13.3	14.1	12.2	13.3	13.1	12.6	11.9	10.5	10.5	6.5	5.0	3.0	
	M			8.0	11.0	6.2	11.7	9.2	9.6	9.9	9.0	10.7	7.1	9.4	7.5	4.0	3.0	
	(N)			(1)	(1)	(6)	(19)	(27)	(56)	(28)	(46)	(20)	(14)	(11)	(2)	(1)	(2)	
TA=35	RC				17.5	15.5	15.3	14.8	14.66	13.5	13.8	12.6	11.5	9.2	11.0		9.0	
	M				16.0	11.0	14.7	12.9	12.6	10.9	12.3	10.5	10.3	8.5	8.7		3.0	
	(N)				(2)	(22)	(17)	(56)	(32)	(32)	(60)	(21)	(12)	(10)	(3)		(1)	
TA=40	RC		16.0	21.0	15.0	15.1	15.8	15.8	15.8	15.5	15.2	15.2	13.6	11.3	12.3	11.5		
	M		14.0	16.0	15.4	14.0	14.0	15.9	16.0	15.6	14.8	14.0	12.6	13.3	9.8	18.0		
	(N)		(1)	(1)	(9)	(10)	(15)	(63)	(34)	(31)	(29)	(33)	(19)	(4)	(4)	(2)		
TA=43	RC			16.8	15.3	17.3	16.9	16.4	17.1	15.4	15.9	15.5	13.1	12.3	14.3			
	M			19.2	10.0	17.5	17.0	17.2	17.8	15.0	15.8	15.6	10.6	14.1	12.0			
	(N)			(5)	(3)	(18)	(14)	(25)	(33)	(50)	(46)	(17)	(8)	(9)	(3)			
TA=45	RC			23.5	20.3	18.6	18.5	17.1	17.0	16.8	15.0	15.1	14.2	14.1	13.5	18.0		
	M			22.5	16.0	17.1	18.0	16.0	19.1	15.9	15.7	16.0	15.3	10.5	19.0	18.0		
	(N)			(2)	(7)	(11)	(44)	(34)	(52)	(44)	(39)	(41)	(18)	(8)	(2)	(1)		
TA=50	RC		16.0		17.4	18.9	19.4	18.4	18.0	19.2	17.6	17.2	14.9	16.0	16.8			
	M		20.5		21.1	20.3	20.4	21.8	19.3	22.5	20.2	21.8	15.6	20.9	16.6			
	(N)		(2)		(7)	(27)	(20)	(37)	(32)	(43)	(76)	(18)	(8)	(8)	(5)			
TA=55	RC		22.5			21.0	21.0	20.0	19.4	19.5	18.7	19.8	13.0	17.7				
	M		28.5			23.6	22.1	23.2	24.1	23.8	21.4	25.9	17.0	14.7				
	(N)					(28)	(33)	(31)	(49)	(87)	(15)	(20)	(1)	(3)				
TA=60	RC				22.0	22.0	21.3	21.7	20.9	20.3	20.8	21.4	24.0	11.0				
	M				27.0	22.0	24.9	24.7	28.1	25.5	26.2	24.1	28.0	8.0				
	(N)				(3)	(2)	(20)	(27)	(76)	(39)	(48)	(14)	(1)	(1)				
TA=70	RC							24.3	25.5	22.4	20.0							
	M							33.4	30.9	29.5	27.0							
	(N)							(7)	(54)	(42)	(2)							

(N) = Number in this category

RC = Reading Comprehension mean score

M = Mathematics mean score

TA = Total Ability raw score (0 to 80)

2. In Our Experimental Group : In Chapter III we defined under-achievement in terms of achievement relative to total ability, following Thorndike [12] and Rutter and Yule [11]. The rationale for this procedure is given in Thorndike. Regressions of achievement scores (Mathematics and Reading Comprehension separately) on Total Ability scores of the whole NCDS population were used to predict an individual's achievement scores, given his Total Ability score. Actual scores for M or RC below the predicted values were then called underachievement in M or RC relative to the population. For each of M and RC the severity of the underachievement was measured in standard errors (s.e.) of estimate associated with the appropriate regression equation. Approximately 68% and 95% of all scores will lie within 1 s.e. and 2 s.e.'s respectively, of their predicted values ; that is 16% and 2½%, respectively, of all subjects will be under-achieving by more than 1 s.e. or 2 s.e.'s relative to the population.

Using the regression equations and standard errors calculated in this way for the whole NCDS population, we examined the 56 children of the E-group relative to this total population.

Of the 56 E-group children, 17 were under-achieving by at least 1 s.e. on R.C. and 11 of these by more than 2 s.e.'s (10 times the population rate). 16 were underachieving by at least 1 s.e. on M, and 2 of these by more than 2 s.e.'s (twice the population rate). 11 children fell into both 1s.e. underachieving groups. The most severe underachievers in the E-group were 8 boys and 3 girls in RC and 2 girls in Mathematics. Altogether, 35 of the E-group scored below expectation in both subjects, while only 7 scored at or above expectation in both subjects. Chi-squared tests showed that both the dichotomous achieving/underachieving and categorized achievement groups (i.e. $\geq$ expected, > 1 s.e. below expected, 1 to 2 s.e. below expected, and more than 2 s.e.'s below expected) were significant, $p \doteq 0.01$, for both RC and M for the E-group relative to T.

This also supports our dismissal of the 'error' hypothesis of the origins of large V-NV differences. For this hypothesis predicts random errors, and a random series of errors would contain roughly equal numbers of scores which were above and below the actual true level. This would give rise to as many apparent over-achievers as under-achievers ; and we have just seen that this was far from the case.

Correlates of Underachievement Within the E-Group

As we noted from Table 8.5, achievement scores tended to be higher with higher Verbal components of Total Ability. We might therefore expect that underachievement would be worse when Nonverbal ability exceeds Verbal ability. To the extent that, of the 35 E-group children whose achievement scores were below expectation in both RC and M, 33 had higher NV scores and 2 had higher V scores, this expectation was borne out. Also, of the 7 E-group children whose scores were at or above expectation in hoth RC and M, 6 had higher V components. Moreover, all 11 of the 'severe' underachievers in RC (more than 2 s.e.'s below expected score) had higher NV components. However, the 2 'severe' underachievers in M both had higher V components.

From the above findings, we can derive mixed support for the 'developmental' hypothesis that V and NV abilities develop at different rates and that large V-NV differences arise because of fast developers associated with one direction of difference and slow developers associated with the other. For since Verbal ability was found to be the dominating influence on Reading and Mathematical development at age 11 (see p.21), we would predict that V>NV were the fast developers, who might then be supposed to be high achievers. This was supported to the extent that six of the V>NV were 'overachievers' in both RC and M (in the wide sense of "above expectation") while only two were underachievers in both RC and M (again in the wide sense). But there were enough exceptions to throw doubt on such an explanation. Moreover, this hypothesis would predict a flatter distribution of V-NV differences (in line with the distributions found in investigations of Piagetian development).

Tables A and B in Appendix 8.1 give more details of how underachievement in Reading Comprehension and/or Mathematics, and its severity, vary with the direction and magnitude of the Verbal-Nonverbal difference and the child's sex.

The relationships of underachievement with social class, sensory defects, emotional variables, pregnancy and birth factors, and coordination variables within the E-group are detailed in Appendix 8.1 tables C, D, E and F, G and H, respectively.

Table C of Appendix 8.1 shows that there is little evidence of consistent environmental influence leading to the large V-NV differences within the E-group; in particular higher Verbal scores were not confined to the higher social classes, nor higher Nonverbal scores to the lower social classes.

Both underachievement related to teachers' ratings on a battery of emotional behaviour variables (the Bristol Social Adjustment Guides), and underachievement related to pregnancy and birth factors showed fairly consistent trends; the other relationships did not. In both the former cases, the greater the underachievement the more prevalent the factors (Tables E, F, G in Appendix 8.1).

From Tables E and F of Appendix 8.1, emotional disorders also seem improbable as a major source of V-NV discrepancy, although we should have a much stronger case for rejecting this explanation if the NCDS data had contained V and NV ability measures at age 7 as well as at age 11. As it is, we cannot reject this theoretical source of discrepancy unless we extrapolate back from V-NV differences at age 11 to similar discrepancies at age 7. At age 7 only one child from the E-group socred in the top 10% of teachers' ratings on a battery of emotional behaviour variables (the BSAG) but this child and 5 others scored in the top 10% at age 11. Thus behaviour ratings declined from ages 7 to 11, whereas differences in V and NV abilities would then have been fairly constant over this period.

Although, within the E-group, emotional behaviour tended to vary with degree of underachievement, this may be more indicative of the child's reaction to underachievement than of a causal factor. This interpretation is supported by the decline in behaviour ratings from 7 to 11 years which accompanied experiences of poor achievement.

These trends within the E-group reinforce our conclusions on page 14 drawn from comparison of the E-group with the total NCDS population.

The relationships between neurological (in the widest sense) variables and V-NV discrepancies and underachievement are not strong enough to identify neurological malfunction or brain damage as causes (or indeed, as having occurred) in these cases. However, there is some indirect evidence which gives this some support. The E-group was found to be significantly different from the population on a number of factors relating to pregnancy and birth ; these factors were also significant in the Perinatal Mortality Survey. In that study the cause of death was often some form of brain damage (Butler and Bonham [13].) Moreover, in cases of known brain damage, large V-NV discrepancies and specific or general underachievement are quite common (e.g. Johnson and Mycklebust [14]). The E-group also displayed a lack of coordination such as 'poor control of hands', 'poor physical coordination', 'clumsy', 'unsteady standing on one foot', 'unsteady walking backwards on a straight line', 'catching a ball with one hand', etc. (as we have noted, these coordination differences were more pronounced at 7 and 16 than at puberty when most children are experiencing temporary physical disturbances). Moreover, insofar as some of these children were relatively slow early mental developers (mother's reports of whether they were talking by two years), signs of their later lack of achievement were detectable early in life. Within the E-group itself, underachievement and the incidence of abnormal pregnancy and birth factors tended to increase together.

On the basis of this present study, based on the NCDS data, we can say neither that large V-NV differences necessarily lead to underachievement, nor that such large differences always occur with factors suggestive of brain malfunction. However, we can say that underachievement and factors which may be indicative of brain malfunction do occur significantly often in cases of large V-NV differences.

MATHEMATICS AND THE E-GROUP

Two Mathematical Underachievers

The two members of the E-group showing the largest Mathematical deficits were both girls and both had V>NV. As we saw in Chapters IV and V, this was also the most common pattern among Mathematical underachievers with large V-NV differences that we found in our case studies.

The achievement test records for these two children are shown in Table 8.6, indicating their consistently poor Mathematics performances.

These two girls had Mathematics scores at age 11 which were 14 and 16 points (more than 2 s.e.'s), respectively, (out of 40) below the scores expected on the basis of their TAs. At that age, one was achieving in Reading Comprehension, the other was under-achieving by 1 s.e., although they had had identical high scores on the Southgate Reading Test at age 7, and the second girl had the higher Verbal ability score at age 11.

TABLE 8.6

Case No.	Age	TA	V	NV	RC	M	Copying Designs
50	7				29/30	4/10	7/12
	11	44/80	31/40	13/40	19/35	3/40	6/12
	16				29/35	4/24	
55	7				29/30	1/10	6/12
	11	42/80	32/40	10/40	9/35	0/40	6/12
	16				13/35	2/24	
Population	7				23.3/30	5.1/10	7.0/12
Means	11	42.9/80	22.1/40	20.9/40	16.0/35	16.6/40	8.3/12
	16				25.3/35	12.8/24	

ACHIEVEMENT RECORDS FOR TWO WORST MATHEMATICS
CASES IN E-GROUP

Portraits of these two children, from the teachers' and doctors' points of view, are presented in Appendix 8.2. Both had abnormal pregnancy and birth data, later 'neurological' indicators (frequent headaches, poor control of hands, poor physical coordination, general motor handicap), both were cross-lateral (hand-eye) to some degree. The contrasts between these cases are interesting from the social and emotional angles. For at age 7, these girls both scored 29/30 on the Southgate Reading Test, at 11 they both had well above average Verbal ability scores, and they were both good attenders. However, one was from social class 2, had at least one fairly interested parent, and went to an independent school ; the other was from social class 5, had no interested parent, and was sent to a special school for 'backwardness'. The first girl kept up her above-average performance in Reading and found an area in which she had outstanding ability (music?), although her Mathematics continued very poor ; and although her score on the BSAG declined from 2 to 11 between 7 and 11 years, her behaviour was never a cause for alarm. The second girl fell further and further behind with both Reading and Mathematics ; and her behaviour, which at 7 was marginally maladjusted, due mainly to anxiety and inconsequential behaviour, remained maladjusted at 11, with elements of depression, anxiety, restlessness, babyishness and especially hostility.

Less Severe Mathematical Underachievers

The next worse performers on Mathematics achievement at age 11 had scores which were 10 (1 case) and 9 (5 cases) points below expectation (approximately 1.5 s.e.'s). Their achievement records are given in Table 8.7.

TABLE 8.7

ACHIEVEMENT RECORDS OF NEXT SIX POOR MATHEMATICS CASES IN THE E-GROUP

CASE NO.	SEX	AGE	TA	V	NV	RC	M	Copying Designs
33	B	7				10/30	4/10	8/12
		11	38/80	11/40	27/40	6/35	4/40	8/12
		16				5/35	3/24	
8	G	7				7/30	3/10	9/12
		11	30/80	4/40	26/40	2/35	1/40	7/12
		16				17/35	3/24	
9	B	7				8/30	4/10	8/12
		11	36/80	10/40	26/40	12/35	4/40	9/12
		16				missing		
20	B	7				0/30	0/10	5/12
		11	33/80	8/40	25/40	2/35	2/40	8/12
		16				missing		
28	B	7				15/30	5/10	9/12
		11	38/80	11/40	27/40	12/35	5/40	8/12
		16				missing		
56	B	7				6/30	2/10	8/12
		11	35/80	8/40	27/40	9/35	3/40	9/12
		16				missing		

These children clearly represent a different category : their general ability is below average, all have higher Nonverbal scores, and even given their low abilities all are underachieving on both Mathematics and Reading Comprehension (the latter by 1 s.e. in case 56, by 2 s.e.'s in cases 8, 20 and 33). All have reasonable scores, above average given their Total Ability scores, on the copying designs tests.

So much data at 16 years is missing for this group of children that we cannot assess their performance beyond eleven years. The two cases where we do have 16 year data suggest that consistently poor performances continues throughout school life.

In these cases poor Reading could be a contributory factor to poor Mathematical performances. Difficulties with comprehension of concepts could underlie both the Mathematics and Reading deficits, as could difficulties with understanding symbols. Difficulties with symbol reproduction and spatial relationships (e.g. the formal setting out of Mathematical 'sums' in vertical columns) are less likely to cause difficulties in view of their scores on the Copying Designs test.

Mathematical Achievement and Verbal/Nonverbal Abilities

From these studies and from Table 8.5, it seems that V and NV abilities contribute in different ways to Mathematics and Reading Comprehension scores. The latter were very much more tied to the Verbal component as would be expected ; whereas the Mathematics scores tended to have two maxima corresponding to different combinations of V and NV for a given TA score. For Mathematics in the E-group a certain degree of each ability seemed necessary (as suggested by table 8.5) ; thus for girls, no child with $V \geq 28$ was achieving at or above expectation in Mathematics if NV was < 13, and no child with NV $\geq$ 24 was achieving in Mathematics if V was < 15. (Raw scores). For boys in the E-group, no child with V $\geq$ 28 was achieving at or above expectation in Mathematics if NV was < 10 (< 13 with one exception) ; and no child with NV $\geq$ 28 was achieving if V was < 9. However, V and NV components were not of equal weight, since, of the children with V > NV, approximately half were achieving at or above expectation in Mathematics (5/11 girls, 3/6 boys) ; whereas, of the children with NV > V, approximately one tenth were achieving at or above expectation (0/8 girls, 4/31 boys).

This study of the NCDS data, and particularly of the E-group, with regard to large V-NV differences leaves us with many unanswered questions. One of the most intriguing of these is why some E-group children managed to score at or above expectation in RC or M or both, while others did not. Were these errors of measurement? Were some large differences due to natural phenomena and other pathological? Or were social and educational factors able to mitigate the effects of large differences in some cases? It is likely that all of these factors played some part. In particular, from the point of view of our investigation of dyscalculia, it seems very likely that neurological deficits were implicated in some cases, particularly the two severe mathematical underachievers

A second group of questions : Are directional differences important in (i) incidence of underachievement, (ii) type of deficit leading to underachievement, (iii) type of remediation required, (iv) effectiveness of remediation?, may be important from an educational standpoint. Our data suggest that the answers to (i) and (ii), at least, may be in the affirmative. For in this study of the NCDS data, we found fewer underachievers among children with very large V-NV differences in the direction V>NV ; and also some indication that poor copying designs scores were linked to V>NV but not to NV>V.

CASE STUDIES IN LOCAL SCHOOLS

Three Sixth-Form Girls

Our second source of data on large V-NV differences came from case studies of individual children in local schools. We shall briefly recall the relevant details from Chapters IV and V.

As we saw in Chapter V, our attention was first drawn to the V-NV discrepancy syndrome by three cases referred to us by local schools. These cases, all girls, stood out in the schools concerned because each was known to have considerable academic ability, with at least 8 'O' level passes with good grades, and each was expected to pass 'A' levels easily in her chosen subjects, yet each had failed 'O' level Mathematics.

Each of these girls was concerned at her failure in Mathematics (they each wanted 'O' level Mathematics to go to University), and somewhat puzzled by it. One of them expressed it as "I know I'm intelligent, so why can't I do Maths?" Two were going to try 'O' level again, one had given up, when we first met them.

FIGURE 8.2

K'S PERFORMANCE ON A MATHEMATICS TEST

NAME : K TEST : N.F.E.R. BASIC MATHEMATICS TEST FG 22-1-82

Q1-4	Decided on trial and error strategy. Tried □ ≡ + then □ = − and ◇ = + followed immediately. Next tried O = X, which left Δ ≐ ÷ and this fitted.
Q5	Counted on fingers even for + and − ; checked − by adding back. 11 − 3 + <u>16</u> = 24.
Q6	Decimalised 4 ÷ 5. But then produced 4 ÷ 5 x 10 = 12.5.
Q7	40 ÷ x = 4 x = 40 x 4 = 160. !
Q8	3 + x − 2 = 5 3 + x = 7 x = 4. Correct.
Q9	19 − 13 = 6 and 13 − 10 = 3. Filled in missing digits correctly.
Q10	First tried addition law, then hit on multiplication, writing 1/4 = 4/16 and filling in the other fractions correctly.
Q11	Worked out L.H.S. = 45 R.H.S. = 48, filled in < (correctly).
Q12	Worked out L.H.S. = 6 R.H.S. = −6, filled in < (wrongly).
Q13	Worked out L.H.S. = 8 ÷ 15 = $1\frac{7}{8}$ R.H.S. = 15 ÷ 8 = 0.54 (after doubts), so L.H.S. > R.H.S.
Q14	Worked out L.H.S. = 5 x 8 = 40, R.H.S. = 24 + 16 = 40, so put = sign.
Q15	Wrote down 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 are correct answers so 55, 65 are incorrect.
Q16	Counted large step has 8, small step has 4, so 12 cubes.
Q17-19	Wrote down 111, Sheffield, 38 + 326 = 364. No hesitation at all.
Q20-22	Correctly picked out percentages and decimals. No hesitations. On Q21 remarked "20 x 4 = 80".
Q23	Correctly perceived after hesitation.
Q24	Correct.
Q25	Correct.
Q26-27	Used trial and error − guessed correctly what to try first.
Q28	Tried +, then − ; finally hit on x, ÷.

Q29-30 Drew mirror images without hesitation.

Q31 "That is ½ and that is 2. ½ into 2 goes 4, so it's ¼. No it's ⅛. No it's ¼".

Q32 "4 and 3 is 7, times 6 is 42, take away 2 is 40, so it's not b c a and it's not a b c. Try b a c. 7 minus 2 is 5, times 6 is 30. Try a c b. 2 times 6 is 12 and 3 is 15."

Q33 "Not a b c given. Try a c b - no. Try b a c. 8 minus 4 is 4, times 3 is 12. No. Try b c a. 6 and 2 is 8, times 3 is 24. Yes."

Q34 "6 goes to 13, 3 goes to 7. 6 times 2 is 12, and 1 is 13. So 4 goes to 9."

Q35 Accidentally omitted.

Q36 Wrote $1 \rightarrow 5$. $44 \div 5 = 8\frac{4}{5}$ cm.

Q37 Correctly visualised rotated diagram - aligned rectangle with axes.

Q38-41 Wrote $3^2 = 9$. $3^4 = 27 \times 3 = 81$. $4 \times 9 = 36$. $16/4 = 4$.

Q42 "B goes into A $1\frac{1}{3}$. No. $1\frac{1}{4}$."

Q43 "¼A."

Q44 "1B + 2A". No hesitation.

Q45 "1A .... No. 2A + 2B."

Q46 "Δ + Δ = □ so 4 Δs = *, so ⬭ = 8Δs."

Q47 Wrote - * □ Δ⁚ Correct.

Q48 Wrote ⬭ * □ -. Correct.

Q49 Wrote ⬭ * □ □. Wrong.

Q50-51 Gave up. "I don't know how to do these."

Q52 Correct answer. No hesitation.

Q53 Subtracted next largest from largest. Then "Oh. Not necessarily biggest. So it's Cardiff and Hull."

Q54 "407" (Missed "thousands").

Q55 "1 and 3, 1 and 2." Long pause. Several false starts, then "Area of rectangle is 6 times area of triangle."

The results of our administration of the B.A.S. test battery for each of these girls was shown in Figure 5.1, Chapter V. It is clear from Figure 5.1 that these three cases have factors in common : high Verbal ability (as measured by Similarities, and confirmed by Verbal fluency, Vocabulary etc.), good memory (STM - verbal, Digit span, and visual) and low Nonverbal ability as measured by Matrices. On the embedded figures test all three were field-independent. Apart from the V-NV discrepancies, M tended to perform worse on timed tests, and K on visual-processing strategies.

Although the background information given by these three girls was suggestive of genetic factors in Mathematics difficulties, especially in the case of M, it was inadequate for assessing pregnancy and birth conditions, so that comparison with the E-group in the NCDS data is not possible.

When it came to actual mathematical performances there were again similarities between the three girls. All were able to do mechanical arithmetic and 'stylized' problems (i.e. problems having and 'obvious at-a-glance' method of solution), but all complained of difficulties in finding the correct strategy to solve unknown or mixed problem types, "S"'s difficulties being particularly acute in algebra problems. K and M had had difficulties as far back as junior school, and for K, at least, these had led to frustration and anger at times.

K's performance on the NFER Basic Mathematics Test FG is given in Figure 8.2. She clearly experienced difficulty with division (including interpretation of the symbol ÷, and ratios). Tables and basic Mathematical facts were known, and stylized problems presented no difficulty.

Remediation or By-Pass Strategy : A Digression

We did not undertake any remediation work in this investigation into dyscalculia ; the scope of our enquiry was already wide enough to exhaust our resources of time and materials. Nevertheless, we did have remediation in mind as a possible next step if our work was found to yield specific areas of deficit. For example, we have already suggested that in cases where a short-term memory deficit was indicated, it would be useful to compare remediation based on the 'familiarity of material' theory with remediation (or by-pass strategy) based on the idea of by-passing the deficit by using rough-paper as a memory store.

A similar dichotomy arose in the case of K. Should one attempt remediation based on the promotion of understanding of Mathematics, or should one use her other strengths to by-pass her difficulty in finding correct strategies - in this case her excellent memory?

When attempts to promote an understanding of Mathematics were abandonned and K was taught to recognize problem types together with algorithms for their solutions, she passed 'O'-level Mathematics with a grade B. But her verdict was that she still had no idea why or how her answers had been correct!

OTHER CASE STUDY CHILDREN WITH LARGE V-NV DIFFERENCES

Included in this category are two more sixth-formers from our initial study, with discrepancies of 65 and 79 centiles respectively between their BAS test scores for Matrices and Similarities. Again, they were both girls (but see note in Chapter V on absence of sixth-form boys in our study). One of these, F, was the only subject in our whole study who obtained full marks on the Similarities test. She was described by teachers as 'very lazy' ; we found her strikingly slow, and she did badly on all timed tests, although she did seem to be trying hard. The other girl had always had difficulties with Mathematics, especially with Mathematical problems, and reported that her mother and one brother had difficulties too, but that a younger brother and her father had none.

The only twelve-year-old in our initial study who had a very large discrepancy score was a girl whose Matrices score exceeded her Similarities score by 59 centiles. On the AH3 reasoning test she scored a total of 64 (approximately the 90th centile for her age), with high scores on verbal and perceptual materials (27 and 24 respectively) but a low score on numerical material (13). Her performance on the latter, together with that on a simple mechanical arithmetic test (from the BAS) revealed that strategies were appropriate, but that concepts of place value, fractions, and division of larger numbers were inadequate. Moreover, she frequently misread, or ignored, the operations signs.

All the six children mentioned above had memory scores above the 50th centile for their ages, and all but K (who was cross-lateral

(RH x LE) were Right-lateral for hand and eye preferences.

In our second case-study sample of mathematical underachievers, (see Chapter V) three children had discrepancies of 60 centiles or more between Matrices and Similarities, a girl and a boy with V > NV and a girl with NV > V. Three other children had discrepancies greater than 50 centiles, all were boys with V > NV. Five of these six children were cross-lateral (4RH x LE, one LH x RE). Two of these children also had very poor STMs (≤ 15th centile) and two others had poor memory scores (< 30th centile) in view of their high Similarities scores.

When the children were asked to do the Basic Mathematics Test F-G, working each problem aloud, a fundamental difference within the children with large or fairly large V-NV differences began to emerge. We noticed that, if Verbal ability was higher, the children tended to read the question and say they understood the question but did not know how to begin. On the other hand, if Nonverbal ability was higher, the children tended to read the question and say they did not understand. When a question was explained or rephrased and concepts explained for this group, an appropriate strategy was often produced and the problem solved ; but similar explanations and rephrasing for the high-V group tended to be met with a reiteration that they did not know where to begin and that they had already grasped the question. Perseveration of methods (reluctance or inflexibility in changing strategies) and failure to use relevant information were also observed in this high-V group. For example, the first question (Basic Maths FG) stated that the symbols □, Δ, O, ◇ stand for the operations +, -, x, ÷ in some order. Given that 5 □ 2 ◇ 3 = 6 and 6 Δ 3 O 2 = 9, the problem is to find which symbol stands for each operation. We noticed that, having found □ and ◇, some children deduced that Δ and O must be the remaining two operations, but that the high V - low NV children rarely did so.

Because we had no firm 'neurological' data for our case study children, it is more difficult to pick out likely dyscalculics. On the other hand, 'diagnosis by exclusion' would suggest that most other factors could be ruled out in many cases - especially the sixth-formers K, M and S. Indeed the BAS profiles suggest that some forms of spatial or visuo-spatial deficit may have been involved.

Our case studies do support the finding from the NCDS data that the V>NV and NV>V types of large differences in Verbal-Nonverbal Abilities associated with Mathematical underachievement may be indicative of different types of underlying deficits.

NOTES ON OUR TESTS AND PROCEDURES

1. A word of caution concerning the tests used in our case studies to measure Verbal and Nonverbal abilities is in order here. The tests we used were the subtests Similarities and Matrices of the British Ability Scales. The Similarities test was always administered in full ; it consists of 21 items very steeply graded to cover ages 5 to adult. The shortened form, F, of the Matrices test was usually used ; it consists of 11 items very steeply graded to cover ages 5 to adult. This has meant that centile scores, ability scores

and 'T' scores on these tests (see manual) have been very sensitive to raw scores. This has led to two reservations in the use of these tests and their interpretations as given in the BAS Manual.

For most of our subjects, the use of steeply graded tests seemed justified and presented us with no difficulties since all questions up to a certain level were answered correctly, and all questions above that level were failed. (Although the administration of the tests allows for discontinuation after a certain number of consecutive questions have been failed, we never discontinued these two tests.) But in one or two cases, errors were made at one level and questions at a higher level were answered correctly. Scoring was always to the specifications in the test manual, but we felt rather uneasy at these anomalous cases.

The BAS manual gives tables of 'T'-score discrepancies between pairs of subtests which are significant at the 15% and 5% levels (unfortunately 1% and 0.1% levels are not given).

Converting the 'T'-score discrepancies to centiles shows that discrepancies ranging from six centiles at the upper and lower limits (i.e. first to seventh centiles or 93rd to 99th centiles) between scores on Matrices and Similarities would be significant at the 5% level. Considering that the steepness of the grading on the tests we used implies a centile difference of up to 40 for 1 raw score point on the Matrices test 'F', and a centile difference of 10 for 1 raw score point on the Similarities test, we are inclined to question the BAS norms for subtest discrepancies.

In our study of mathematical underachievers, 5 out of 8 sixth-formers, 1 out of 18 twelve-year-olds from our initial sample, 3 out of 28 twelve-year-olds from our second sample, and 2 out of 26 of our 'normal class' of twelve-year-olds (but see chapter IX) had 'T'-score discrepancies $\geq$ 20. This very high incidence of large discrepancies in our mathematical underachievers certainly supports the NCDS finding that such large discrepancies are linked to underachievement.

2. We should also note that the Similarities test is orally administered and untimed. This means that neither poor reading ability nor speed affect scores on this test (unlike AH3-Verbal) and this would explain some of the anomalies between Verbal ability (as assessed by Similarities) and AH3-V scores (and JVR scores where these were known), apart from any differences in the reasoning processes measured.

The matrices test also differs from other Nonverbal materials used to assess some of our case study children, in that it is not a multiple-choice type (unlike the Raven's Matrices test and the AH3-P perceptual reasoning test). Moreover, although some Matrices questions are best answered by perceptual methods, particularly at the beginning of the test, others require deeper analysis and higher levels of multiple classification (position, size, colour, shape, etc.).

This means that the ability differences which we have assessed cannot be confirmed or disproved by our other measures (e.g. AH3-V and AH3-P), although some support might be inferred from patterns of performance on AH3 subtests.

V-NV DIFFERENCES AND LATERALITY

The NCDS data also allows us to look at links between the Laterality variables which were found to be related to mathematical underachievement and large V-NV differences, with a view to clarifying the issue raised in chapter V regarding the independence of the three 'significant areas of functioning' related to mathematical under-achievement.

Of the 56 E-group children, 43 had laterality data at both 7 and 11 years (13 girls, 30 boys). 11 of the girls (84.6%) were consistently right-handed, one changed from L to R and one from M to R) and 2 were consistently cross-lateral (HxE) (15.4%). Of the boys, 21 (70%) were consistently right-handed, 3 (10%) were consistently left-handed, one (3.3%) was consistently mixed-handed. 5 (16.7%) changed hand preference between 7 and 11. (3 M to R, 2 R to M). Consistent cross-laterality occurred in 7 cases (6 RxL, 1 LxR) (23.3%) and to some degree in two others (one consistently MxL, the other RxL at 7 to MxL at 11).

Only the incidence of cross-laterality among the boys of the E-group was substantially different from the total population frequencies.

When we examined laterality preferences with regard to direction of V-NV differences, we found that consistent cross-lateral preferences were prevalent in girls with V > NV and in boys with NV > V, as shown in Table 8.8. However, numbers were too small to draw any firm conclusions. Certainly this pattern did not hold for our case study

TABLE 8.8

DIRECTION OF V-NV DIFFERENCES AND LATERALITY PREFERENCES FOR THE E-GROUP

SUBGROUP	N	R	L	M	CONSISTENT CROSS-LATERAL	CHANGE OF HAND
V > NV GIRLS	7	85.7%	O	O	28.6%	14.3%
BOYS	6	50.0%	33.3%	O	16.7%	16.7%
NV > V GIRLS	6	83.3%	O	O	O	16.7%
BOYS	24	75.0%	4.2%	4.2%	25.0% (+1 MxL)	16.7%

TABLE 8.9

DIRECTION OF V-NV DIFFERENCES AND LATERALITY PREFERENCES OF CASE STUDY CHILDREN WITH LARGE V-NV DIFFERENCES

SUBGROUP	N	HAND PREFERENCE			CROSS-LATERAL
		R	L	M	
V NV GIRLS	6	100%	O	O	33.3%
BOYS	1	O	100%	O	100%
NV V GIRLS	2	100%	O	O	50%

group with large V-NV differences ; but the ratio of boys to girls and the pattern of directional differences was also different for the case studies. Data for these is given in Table 8.9.

There are other differences between the groups represented in Tables 8.8 and 8.9. All the children in Table 8.9 were underachieving in Mathematics, whereas those in Table 8.8 represent a mixture of achievers and under-achievers in both Mathematics and Reading Comprehension. Of the 7 girls with V > NV in Table 8.8, three who were consistently right handed, one of whom was consistently cross-lateral, were achieving in Mathematics. Of the 6 boys with V > NV in Table 8.8, one of the consistent left-handers and two consistent right-handers, one of whom was consistently cross-lateral, were achieving in Mathematics. None of the NV > V girls was achieving, and of the NV > V boys who were achieving, three were consistently right-handed, and one had changed from mixed- to right-handed.

It is clear that any relationship which exists between V-NV differences, achievement, and laterality preferences must be quite complex (possibly the only link may be a neurological one, in that neurological status may affect all three). It would, therefore, be better to treat them as separate aspects.

CONCLUSIONS

On the basis of the three broad investigations undertaken in this Chapter - a study of the literature, an analysis of the NCDS data, and our case studies of children with large V-NV differences - we conclude that there is some evidence that at least some large V-NV differences have a basis of neurological malfunction, and lead to underachievement in some academic areas. For example, case 50 in our E-group appears to us to be such a case. She certainly exhibits 'soft' neurological signs, has 'significant' events in pregnancy and birth data, appears to have no adverse social, educational, emotional or motivational factors in her data, and clearly experienced difficulty with Mathematics from an early age.

Furthermore, the direction of the V-NV difference may be an indication of the type of difficulty or underlying deficit which leads to underachievement. We suggest, very tentatively, that V > NV may indicate good storage and retrieval of factual knowledge, together with an ability to associate related items, but with an impaired ability to find appropriate strategies, or switch easily from one strategy to another in problem-solving ; with the reverse pattern for NV > V.

FUTURE RESEARCH

Our work on large V-NV differences has brought out a number of areas in which tentative links have been suggested and which we feel warrant further investigation. Some of the problems have been mentioned in the text, but they are collected here for convenience.

1. How persistent are large V-NV differences? Do they increase or decrease with age? How early can they be detected? We found large differences (similar magnitudes) in 12-year-olds and 17-year -olds suggesting that they may be very persistent and constant

with age, at least from puberty. We thought one 9-year-old would be found in this category later, but at 9 years no large V-NV difference between the BAS tests Similarities and Matrices was apparent.

2. Do different tests of Verbal and Nonverbal abilities give different results?

3. By using different tests, can we more exactly identify the deficit (or deficits) involved? The NCDS data, and in particular our study of the E-group suggests that this may well prove to be the case. For among the E-group, achievements in Mathematics and Reading Comprehension varied considerably both between and among the V > NV and NV > V subgroups.

4. Are the mathematical difficulties of the groups V >> NV and NV >> V fundamentally different? Our impression, from observations of our case study children attempting to solve mathematical problems, is that there was a difference between V > NV and NV > V children in our sample. But a more rigorous study should be able to quantify the types of difficulty we have suggested and compare them objectively.

5. If such differences do exist, are the concepts of fluid and crystallised intelligence helpful in explaining these differences?

6. If such differences do exist, are they linked to Mathematics teaching based on mechanical arithmetic with little attention to problem-solving?

7. If such differences do exist the more difficult question is whether we can trace large V-NV differences to the child's early recreational activities i.e. mainly passive (reading and being told facts and stories) or mainly active (finding out for oneself and creating own amusements).

8. If a specific deficit (or deficits) can be identified, can it be remedied? e.g. by problem-solving exercises, by concrete problem-solving, by exercises in translating verbal problems in arithmetic into mathematical symbols, and vice versa.

9. If the deficit(s) cannot be remedied (consistent with neurological malfunction), can its effects on Mathematical achievement be minimised? e.g. by teaching alternative strategies (see the case of K. on page 371).

APPENDIX 8.1

CORRELATES OF UNDERACHIEVEMENT WITHIN THE E-GROUP

The following tables give details of the relationships of underachievement with V-NV differences, social class, sensory defects, emotional variables, pregnancy and birth variables, and coordination variables, within the E-group.

Table A : Underachievement and V-NV Differences

	N > NV		NV > V		Total Cases
Girls	11 cases		8 cases		19
	Reading Comp.	Maths.	Reading Comp.	Maths.	
	4 cases +	+	1 case -	-	
	1 case -	+	3 cases -1	-	
	1 case +	-	1 case -1	-1	
	1 case -	-	2 cases -2	-	
	1 case -1	+	1 case -2	-1	
	1 case +	-1			
	1 case +	-2			
	1 case -1	-2			
Boys	6 cases		31 cases		37
	2 cases +	+	1 case +	+	
	2 cases -	+	2 cases +	-	
	1 case +	-	5 cases -	-	
	1 case +	-1	1 case -1	-	
			7 cases -1	-	
			4 cases -	-1	
			3 cases -1	-1	
			2 cases -2	+	
			1 case -2	-	
			5 cases -2	-1	
TOTAL	17 cases		39 cases		56

- = underachieving   1 = 1 s.d.

+ = achieving   2 = 2 s.d.

Table B : Underachievement and V-NV Differences

	Average %ile differences		
		NV-V	V-NV
Magnitude of underachievement	Achieving on RC and on M	62.0(1)	63.8(6)
	Underachieving (by < 1 s.d) on just one of RC and M	67.3(3)	64.3(6)
	Underachieving (by > 1 s.d) on just one of RC and M	71.0(3)	62.7(3)
	Underachieving (by < 1 s.d) on both RC and M	66.0(6)	61.0(1)
	Underachieving on both RC and M, on just one by > 1 s.d	67.7(19)	No cases
	Underachieving (by > 1 s.d) on both RC and M	66.3(7)	75.0(1)

Table C : Underachievement and Social Class

		Achievement: Reading Comp.	Achievement: Maths	(Higher of V,NV)	(Sex)
Father's social class	Mother Class II	-2RC	-1M	NV	B
	III	+ RC	+ M	V	G
No male head:	III	-1RC	- M	NV	B
	V	- RC	-1M	NV	B
	Unknown	-1RC	-1M	NV	G
Class 1 :	Mother Class II	- RC	-1M	NV	B
		-1RC	-1M	NV	G
	III	+ RC	+ M	V	B
	Unknown	+ RC	-2M	V	G
Class II :	Mother Class II	-2RC	+ M	NV	B
	III	-2RC	- M	NV	B
	Unknown	+ RC	- M	NV	B
Class III (Man)	Mother Class II	+ RC	+ M	V	B
	III	- RC	- M	NV	B
Class III (Man)	Mother Class II	+ RC	+ M	NV	B
		- RC	-1M	NV	B
	III	+ RC	- M	V	G
		- RC	- M	NV	B
		-2RC	-1M	NV	B
		-1RC	-1M	NV	B
		-1RC	- M	NV	B
		-2RC	-1M	NV	B
		-2RC	-1M	NV	B
		- RC	-1M	NV	G
		- RC	- M	V	G
		- RC	-1M	NV	B
		-1RC	-2M	V	G
	IV	+ RC	- M	NV	B
	V	-2RC	- M	NV	G
		-1RC	- M	NV	B
		-2RC	-1M	NV	B
	Unknown	+ RC	-1M	V	G
		-1RC	-1M	NV	B
		-2RC	- M	NV	G
Class IV (Man)	Mother Class II	-1RC	+ M	V	G
		-1RC	+ M	NV	B
		-1RC	-1M	NV	B
	III	+ RC	-1M	V	B
	IV	-2RC	-1M	NV	B
		-2RC	- M	NV	G
	V	- RC	+ M	V	B
		-2RC	+ M	NV	B
		- RC	+ M	V	B
	Unknown	-1RC	- M	NV	B
		+ RC	- M	V	G
Class V	Mother Class II	-1RC	- M	NV	B
		+ RC	+ M	V	G
	IV	-1RC	+ M	V	G
	Unknown	+ RC	- M	V	B
Class not known	Mother Class II	-1RC	- M	NV	G
		+ RC	- M	NV	B
	III	-1RC	- M	NV	B
		- RC	- M	NV	B
		-1RC	- M	NV	B
		+ RC	+ M	V	G
	IV	-2RC	- M	NV	G

Table D : Underachievement and Sensory Defects

Visual Defect at 7 years or 11 years :

Achievement :	Reading Comp.	Maths.	(Greater of V,NV)	Sex	Average Under-scores: Reading Comp	Average Under-scores: Maths
	-2RC	-1M	NV	B		
	-1RC	- M	NV	B		
	+ RC	-1M	V	G		
	-1RC	- M	NV	B	4.2	4.0
	+ RC	+ M	V	G		
	+ RC	+ M	NV	B		
	-2RC	-1M	NV	B		
	- RC	- M	NV	B		
	-1RC	-1M	NV	B		
	-1RC	-1M	NV	G		
	-1RC	-*m	V	G		
Hearing Defect at 7 years or 11 years :						
	- RC	- M	NV	B		
	-1RC	- M	NV	G	2.3	-3.0
	- RC	+ M	V	B		
Visual and Hearing Defects at 7 or 11 years :						
	-1RC	-1M	NV	B	5.0	6.0
No Sensory Defect					3.3	2.8

Table E : Underachievement and Emotional Variables

Total syndrome score 21 or more at both 7 and 11 years (10% of T at each age) :

Score at age 11	Reading Comp.	Maths	Greater of V,NV	Sex	Score at age 7	Average underscores: Reading Comp.	Average underscores: Maths
(25)	-2RC	-1M	NV	B	(21)	8.0	8.0

Total syndrome score 21 or more at 11 years:

(22)	-2RC	-1M	NV	B	(18)		
(23)	* RC	- M	NV	B	(?)		
(29)	- RC	- M	NV	B	(14)	4.6	5.2
(22)	-2RC	- M	NV	B	(?)		
(21)	-1RC	-2M	V	G	(14)		

Total syndrome score 5 or less at both 7 and 11 years (50% of T at each age):

(2)	+ RC	- M	V	G	(0)		
(4)	- RC	+ M	V	B	(3)		
(1)	-1RC	- M	NV	B	(0)		
(2)	- RC	- M	NV	B	(2)		
(3)	+ RC	+ M	V	G	(2)		
(1)	-2RC	-1M	NV	B	(5)		
(4)	-1RC	-1M	NV	B	(?)	0.8	-0.8
(2)	+ RC	+ M	V	B	(0)		
(2)	-1RC	+ M	V	G	(?)		
(5)	+ RC	- M	NV	B	(1)		
(1)	-1RC	-1M	NV	G	(5)		
(2)	- RC	-1M	NV	B	(3)		
(0)	+ RC	+ M	V	G	(?)		

Total syndrome score 5 or less at 7 years only:

(19)	+ RC	-1M	V	G	(0)		
(9)	- RC	- M	NV	B	(5)		
(8)	+ RC	-1M	V	B	(1)		
(6)	-1RC	- M	NV	B	(1)		
(17)	+ RC	+ M	V	G	(0)		
(11)	-2RC	- M	NV	B	(1)		
(17)	-1RC	- M	NV	B	(4)		
(8)	- RC	-1M	NV	B	(4)	2.7	3.4
(9)	-2RC	+ M	NV	B	(0)		
(6)	+ RC	- M	V	G	(0)		
(6)	-1RC	+ M	V	G	(0)		
(7)	- RC	+ M	V	B	(0)		
(11)	+ RC	-2M	V	G	(1)		
(13)	-1RC	-1M	NV	G	(1)		
(19)	-1RC	-1M	NV	B	(2)		
(6)	-1RC	-1M	NV	B	(3)		

Total syndrome score 5 or less at 11 years only:

(0)	+ RC	+ M	NV	B	(12)		
(5)	+ RC	+ M	V	B	(9)		
(3)	-2RC	+ M	NV	B	(12)		
(5)	-2RC	-1M	NV	B	(7)	+3.0	+0.6
(4)	- RC	-1M	NV	G	(18)		
(4)	-1RC	+ M	NV	B	(8)		
(0)	- RC	- M	V	G	(13)		
(2)	+ RC	- M	V	B	(9)		

Total Syndrom score 6 to 20 at both 7 and 11 years:

(8)	-2RC	-1M	NV	G	(16)		
(16)	-1RC	- M	NV	B	(11)		
(12)	-2RC	-1M	NV	G	(9)		
(17)	- RC	-1M	NV	B	(?)		
(7)	-1RC	- M	NV	G	(?)		
(11)	-2RC	- M	NV	G	(17)	6.5	5.5
(6)	+ RC	- M	NV	B	(10)		
(6)	-2RC	-1M	NV	B	(11)		
(9)	-1RC	- M	NV	B	(6)		
(20)	- RC	-1M	NV	B	(8)		
(6)	-1RC	- M	NV	B	(20)		
(15)	-2RC	-1M	NV	G	(10)		
(17)	-2RC	-1M	NV	B	(7)		

Table F : Underachievement and Emotional Variables

Underachievement Groups :	Average 'Total Syndrome' Scores Age 7	Age 11
Achieving on both RC and M	3.8	4.1
Underachieving on just one of RC and M (by less than 1 s.d)	3.3	8.2
Underachieving on just one of RC and M (by greater than 1 s.d)	3.7	6.8
Underachieving on both RC and M, by less than 1 s.d. on each	8.0	8.9
Underachieving on both RC and M, on one by greater than 1 s.d.	8.9	11.1
Underachieving on both RC and M, both by greater than 1 s.d.	8.4	12.5

Table G : Achievement and Pregnancy and Birth Factors

Achievement Group	Description of Cases	Number of Normal Cases
Achieving on both RC & M	1 3-4 weeks premature 1 Mother age 19 4 Normal	4./7
Achieving on one of RC & M, under-achieving on other by < 1 s.d.	1 Breech birth 1 3-4 weeks premature 1 2-3 weeks premature 1 Mother age 19 3 41 weeks pregnancy 2 Normal	2/9
Achieving on one of RC & M, under-achieving on other by > 1 s.d.	1 Breech birth 1 3-4 weeks premature 1 2-3 weeks premature 1 Mother age 35 2 Normal	2/6
Underachieving on both RC & M, by < 1 s.d.	1 Forceps delivery 1 Vertex OP delivery 1 Multiple birth & trauma 1 Bleeding in preg., mother age 35 1 Mother age 37 1 41 weeks pregnancy 1 Normal	1/7
Underachieving on both RC & M, one by > 1 s.d.	2 Breech births 1 5-6 weeks premature 1 4-5 weeks premature 2 3-4 weeks premature 1 Bleeding in pregnancy 2 Abnormal pregnancy 1 Mother age 39 1 Mother age 38 1 Mother age 18 1 42 weeks pregnancy 6 Normal	6/19
Underachieving on both RC & M, by > 1 s.d.	2 No trained person present at birth 1 Abnormal pregnancy 43 weeks 1 Mother age 40 1 Mother age 19, 43 weeks preg. 1 Mother age 20 1 41 weeks pregnancy 1 data missing	0/7

Table H : Underachievement and Coordination

Achievement Group	Description of Cases	Number of Normals
Achieving on both RC & M	1 Poor coord. at 7 & 11 1 Unsteady at 11 1 Condit. affecting neurolog fn. 4 Normal	4/7
Achieving on one of RC & M, underachieving on other < 1 s.d	1 Poor coord. at 7 1 Poor coord. at 7 & 11 3 Coord. scores at 11 1 Coord. scores missing 3 Normal	3/8
Achieving on one of RC & M, underachieving on other > 1 s.d	2 Poor coord. at 7 2 Unsteady at 11 1 Coord. scores at 11 1 Normal	1/6
Underachieving on both RC & M by < 1 s.d.	1 Poor coord. at 7 & 11 1 Poor coord. at 7, unsteady at 11 1 Poor coord. at 7 1 Unsteady at 11 3 Coord. scores at 11	0/7
Underachieving on both RC & M; just one by > 1 s.d.	3 Poor coord. at 7 & 11 2 Poor coord. at 7 5 Unsteady at 11 1 Coord. scores at 11 2 Missing coord. scores 6 Normal	6/17
Underachieving on both RC & M by > 1 s.d.	3 Poor coord. at 7 & 11 2 Poor coord. at 7 1 Unsteady at 11 1 Missing 1 Normal	1/7

APPENDIX 8.2

TWO 'SEVERE' MATHEMATICS UNDERACHIEVERS IN THE NCDS WITH LARGE V-NV DIFFERENCES

These partial profiles have been constructed from NCDS data ; they are subjective insofar as much of the data consisted of assessments by parents, teachers and doctors; ability and achievement scores were obtained on objective tests.

Case 50 : Gestation period and birthweight were not recorded. The child was a girl, her mother was 25 and 5'5" tall and had stayed on at school. There was no recorded bleeding or high blood pressure during pregnancy and no recorded foetal distress at birth ; but it was an extracted breech birth.

The child walked by 1½ years and talked by 2 years. The family moved once before the child started school ; they were of social class 2 (R.G.'s classification) and the father had also stayed on at school. The child was the second of three and cared for by her own father and mother.

The child did not attend pre-school ; she started full-time school at 4½ to 5 years - at a private infants school. She started phonics at 5 to 5½ years and 'sums' at 5½ to 6 years. She settled down at school within a month (teacher and mother agree). Parents had asked to discuss the child with the teacher ; the mother was said to show some interest, the father little or none.

At 7, the child was in a class of 20 (formation of class recorded as "other arrangement" i.e. not a year group, not by ability within a year group etc.) and was a good attender (0 absences in last term). The teacher rated her as average on oral ability, awareness of the world around, reading, creativity and number work ; she was on basic reader book 4. She scored 29/30 on the Southgate Reading test, 4/10 on the Problem arithmetic test, and 7/12 on Copying designs.

The teacher rated her as having somewhat poor control of hands, somewhat poor physical coordination and always moving about somewhat. Her mother said she was happy at school, sometimes finding difficulty in settling to anything, sometimes worrying and as having frequent headaches.

She had a total syndrome score of only 2 on the emotional behaviour ratings, and made only one mispronunciation on the speech test.

She was described as tall for her age, weighed 69 lbs. and had a head circumference of 21.5". She was Right-handed, mixed-footed and left-eyed (cross-lateral H x E)

By 11 she was at an independent school, where she was again a good attender (9/238 absences). She was then rated as being of average oral ability and general knowledge, having little ability in

Mathematics, but her use of books was above average and she was said to have outstanding ability in some area (not specified). She had a Verbal score of 31/40, Nonverbal 13/40, Reading comprehension 19/35, Mathematics test 3/40 and Copying designs 6/12.

Unfortunately, parental and medical data at 11 years are both missing.

She then had a total syndrome score of 11 on the emotional behaviour ratings, and was said to be an outsider. She was again described as tall for her age.

At 16 years she was attending a co-educational comprehensive school, where 33% of the boys and 20% of the girls were taking public examinations. She had a fairly good attitude to school work (a score of 10 on the academic motivation scale), and her attendance was fairly good.

She was rated as of below average mathematical ability and unable to do everyday calculations (but she was in a middle ability mathematics class(!), as average in social studies, as above average in English and Modern Languages and practical subjects. She rated herself in the same way as the teachers, and also rated her science, art and sports all average and music above average. She scored 29/35 on the Reading Comprehension test and 4/24 on the Mathematics test.

She had been prescribed glasses but vision was thought by the doctor to be no handicap. She made no mispronunciations on the speech test. She was slightly unsteady standing heel-to-toe, definitely unsteady hopping on either foot, showed mild clumsiness, made five catches with her R.H. and three with her L.H. The doctor found a mild general motor handicap but thought it would cause no interference with her life. The girl was 169 cm. tall and weighed 73.48 kg.

She was said to worry and be on her own somewhat, was rated as more than average cautious and flexible, and as average lazy. Her parents were satisfied with the school and sometimes argued with the child over homework.

Hospital admissions, and contact with psychologist or psychiatrist were both missing.

Case 55 : Gestation period was above normal (302 days), but birth-weight was within 1 S.D. of average. The child was a girl, her mother was 27 and 5'1" tall and had not stayed on at school. There was high blood pressure during pregnancy (mild pure toxaemia) and the pregnancy was also recorded as abnormal (abnormality unspecified). The birth was a spontaneous delivery and no foetal distress was recorded.

The child walked by 1½ years and talked by 2 years. The family moved once before the child started school ; they were of social class 5 and the father had not stayed on at school. The child was the second of three and cared for by her own father and mother. There was mental subnormality in the family.

The child had attended a LEA nursery class (under 3½ years) ; she started full-time school at 5 to 5½ years - at a LEA Junior and Infant school. She started phonics at 5 to 5½ years and 'sums' at 6½ to 7 years. She settled down at school within a month (mother). Neither parents nor teacher made initiatives to discuss the child ; mother and father were said to show no interest.

At 7, the child was in a class of 39, formed by age within the year group, and had an 83% attendance record. The teacher thought she would benefit from help with backwardness and was likely to need special schooling in the next two years (she was referred because of these difficulties). The teacher rated her as above average in oral ability and reading, average in awareness of the world around, below average in creativity, and very bad in number work. The child was reading at basic book 3 level. She scored 29/30 on the Southgate reading test, 1/10 on the problem arithmetic test, and 6/12 on Copying Designs.

The teacher rated her as having somewhat poor control of hands and as certainly always moving about. Her mother said she was happy at school.

She had a total syndrome score of 21 (anxiety and inconsequential behaviour most prominent) ; she made no mispronunciations on the speech test.

She was described as of average size, weighed 45 lbs. and had a head circumference of 20.0". She had a visual defect which was thought not to be a handicap. She was mixed-handed, mixed-footed and left-eyed. (Some degree of cross-laterality.)

By 11 she was at a special school receiving help for educational or mental backwardness, and was a good attender (20/400 absences). Her general knowledge, oral ability, and use of books were all rated below average and her number work as very bad. She had a Verbal score of 32/40, Nonverbal 10/40 ; Reading comprehension 9/35, Mathematics test 0/40, and copying designes 6/12.

The parental questionnaire is missing, as are most of the medical data. The child was described medically as 'receiving special educational treatment', 'ESN', 'congenital condition'.

She had a total syndrome score of 21 on the emotional behaviour ratings (she was now depressed, anxious, restless, babyish and especially hostile), and was said to be an outsider. She was again described as of normal size.

At 16 years she was attending a co-educational comprehensive school, where none of the children were taking public examinations. She had a poor attitude to school work (a score of 21 on the academic motivation scale) and her attendance was fairly good.

It was thought that special educational treatement was no longer required and that mental retardation was now no handicap. However, her teachers rated her as very bad on English, Maths, Languages, Science, Social Studies and practical subjects ; and thought that help with backwardness was desirable. She rated herself average at English, Science and Sport and as never having studied Mathematics, Art, Music or Practical subjects. She scored 13/35 on the Reading Comprehension test and 2/24 on the Mathematics test.

Some data were missing (hospital admissions, contact with psychiatrist or psychologist, glasses prescribed, behaviour difficulties, physical or sensory disabilities).

She made no mispronunciations on the speech test. She was slightly unsteady standing heel-to-toe. She was 154 cms. tall and weighed 45.81 kg. She had been involved in a road accident.

Teachers rated her as still somewhat restless, not liked by other children, worrying, miserable, unresponsive and inert, resentful and aggressive ; and as certainly solitary, having fights and quarrels. They also thought she was average cautious, above average flexible and above average hardworking. Parents were satisfied with the school.

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CHAPTER IX

A 'NORMAL' CLASS OF 12 YEAR OLDS

In a tentative effort to put the findings of this study into perspective, the test battery, excluding the diagnostic mathematics test, was administered to a 'normal' class of 12 year-olds, which was known to contain at least one mathematical underachiever. First-hand comparisons were made between the samples of mathematical underachievers and this normal class, with regard to the three 'significant areas of functioning' discussed earlier. The test battery was used to identify the underachiever.

We have already pointed out in Chapters IV and V that our case studies in local schools had so far involved only children who were underachieving in Mathematics. Our observations that among these children some had very poor Short-term Memory scores, some had large Verbal-Nonverbal differences, and that there seemed to be a very high proportion of cross-laterality or non-right laterality cases, were based on theoretical norms derived from test standardisations or empirical studies of very large samples.

In spite of the theoretical and previous research evidence that we found to be consistent and illuminating with respect to our findings, the samples involved in our case studies were very small and spread over a number of schools and pupil ages. We have nevertheless argued that our observations may have some validity : from our evidence and the theoretical background there appear to be a number of neurological deficits related to mathematical underachievement. Nevertheless we felt that a tentative effort to consider our findings in relation to a normal 'average' class would be worthwhile, both in terms of checking on our procedures and test battery and also to consider the correlates of mathematical underachievement in a 'normal' group of children in order to make more first hand comparisons.

In essence the latter provides a very limited validity investigation to consider how discriminating our findings might be in drawing attention to mathematical underachievers. It was felt worthwhile to ask if the group of tests would help to identify undiagnosed cases of mathematical underachievement, in practice to see if our test battery would help in identifying any severely underachieving pupils in a class of average children.

Our investigations of these two aspects, i.e. to check the findings of our tests with a 'normal' group to see that our test battery and procedures seemed alright and to see if any of the three 'significant areas of functioning' would appear, form the basis of this Chapter.

CHOOSING THE SAMPLE

As part of a study of sex differences in achievements and attitudes to certain subjects, including Mathematics (ongoing study based at the University of Bath), approximately 2,000 11 to 12 year-olds in local comprehensive schools had been given ability and Mathematics attainment tests during the previous year.

On the basis of the latter tests, the NFER's Mathematics attainment Test E-F and the NFER Verbal Reasoning Test EF, a regression of

Mathematics scores on Ability scores was used to identify the coded identities of serious mathematical underachievers. The schools and forms of a number of these underachievers (achieving three standard errors below expectation) were located for us by the project organisers, and we obtained permission from one school to test the whole of one form of pupils which was an 'average' ability banded class, containing at least one underachiever. The name(s) of the underachiever(s) was (were) not disclosed to us until our testing had been completed and our results analysed.

THE TEST RESULTS

The results of our testing of the class of 'normal' children are presented in Table 9.1 in summary form. The class consisted of average to above-average ability children whose achievements in most areas were average to good.

We noted that no child had a Digit Span score below the 30th centile for the relevant age group (BAS norms). Moreover, the more able children in the class tended to have higher memory scores. It therefore seemed unlikely that memory scores would disclose the underachiever on this occasion.

From Table 9.1 we can see that forward span scores were in the range 22 to 34 (corresponding to 6 digits with one repetition, and to 8 digits without repetition, respectively). Questioning of some of the children revealed that some of the higher scores were almost certainly due to practice effects carried over from the Simon memory

TABLE 9.1

SUMMARY TEST SCORES OF 'NORMAL' CLASS IN SCHOOL G

CHILD	AH3 V - N - P	AH3 TOTAL	LATERALITY H - F - E	L - R	WALKING BACKWARDS	DIGIT SPAN ACTUAL SCORES FORWARDS (No. of digits = (n/5 < 1))	DIGIT SPAN ACTUAL SCORES BACKWARDS	MATRICES %ILES	SIMILARITIES %ILES
a	18 - 24 - 27	69	R - R - R			23	19	55	86
b	21 - 17 - 21	59	R - R - L	*		22	13	30	73
c	21 - 12 - 25	58	R - M - R			24	14	53	73
d	25 - 21 - 22	68	R - R - L			34	25	73	92
e	23 - 27 - 30	80	R - R - M			33	15	53	36
f	26 - 27 - 30	83	R - R - R			22	14	8	36
g	18 - 22 - 21	61	R - R - R			22	18	75	56
h	22 - 22 - 26	70	R - M - R			25	23	75	56
i	16 - 16 - 16	48	R - R - L		*	28	25	55	75
j	18 - 21 - 26	65	R - R - R		*	28	23	30	73
k	18 - 19 - 20	57	R - R - R			24	15	30	73
l	18 - 11 - 24	53	R - R - R			23	15	30	36
m	19 - 20 - 23	62	R - M - M		*	23	18	28	69
n	14 - 13 - 19	46	R - R - R			26	11	53	73
o	21 - 24 - 22	67	R - R - R			26	18	80	94
p	28 - 10 - 23	61	R - R - R			33	22	32	94
q	23 - 18 - 25	66	R - R - R		*	28	18	30	93
r	26 - 20 - 28	74	R - R - R			26	25	75	84
s	18 - 21 - 17	56	L - M - R			34	22	53	73
t	17 - 13 - 17	47	R - M - R		*	28	17	53	75
u	24 - 17 - 21	62	R - R - R			23	20	75	84
v	27 - 19 - 31	77	R - R - R	*		22	21	80	99
w	23 - 23 - 25	71	L - L - L			22	22	80	75
x	18 - 18 - 24	60	R - R - L		*	26	19	30	84
y	21 - 16 - 23	60	R - R - R		*	28	13	55	94
z	12 - 16 - 17	45	R - R - R		*	22	13	30	73

(a) to (i) boys;   (j) to (z) girls.

game. Backward span scores ranged from 11 to 25 (corresponding to 4 digits with repetitions, and to 6 digits without repetition, respectively). It is usual to find that backward span is one or two digits less than forward span (see Chapter VII), so that these ranges are quite normal. However, some children did have large discrepancies between forward- and backward-spans (26, 11), (33, 15) and (28, 13). Such differences may be an indication either of the use of practice or strategies which inflate the forward-span score, or of sequential processing difficulties (i.e. in changing the order of the digits before repeating them back) which depress the backward-span score. None of these three children had specific difficulty with numerical material on the AH3 test (and, using the regression of Mathematics test scores on Ability test scores it later transpired that none was underachieving by more than 1 standard error in relation to the 2,000 children in the project).

The table of results (9.1) shows that 11 of the 26 children had anomalous (non-right) laterality of hand, foot or eye, 5 of these being cross-lateral (H x E). [We later found that only of of these children (a boy who preferred his right hand and left eye) scored at or above expectation on the Mathematics test, while 5 of the right-homolateral children did so.] Comparison with the NCDS data suggests that these rates of anomalous and cross-lateralities are lower than the rate for the general population; possibly this is in part due to the proportion of girls in the present sample.

As we have seen from the NCDS and case study children, laterality variables alone do not predict or rule out underachievement (Chapter VI), and without further evidence we did not feel justified in nominating any of the anomalous cases as a likely mathematical underachiever. None of the children had real difficulty with Left and Right (four confessed to occasional difficulty and two hesitated in our tests); and none were very unsteady in the walking backwards test.

Comparison of Matrices and Similarities scores in Table 9.1 disclosed three cases in which discrepancies exceeded the 'T'-score discrepancy of 20 which we have taken to be significant. These cases consisted of one boy and three girls, all of whom had higher Similarities scores.

As some of the testing had been done individually, we had the added advantage of some personal knowledge of the pupils, and at this stage were able to note that the boy had appeared somewhat off-hand in the 1 - 1 testing situation, and that one of the girls had been absent on two occasions when we visited the school. Considering each of the three in more detail revealed the following.

None of the three had difficulties with right and left, and only the second girl was at all unsteady on the walking backwards test; all three were right-handed, right-footed and right eyed. Because of the non-significance of the Digit Span scores compared with our two samples of mathematical underachievers, and because of the lack of neurological signs to back up the anomalous laterality cases, and because of the significance of these three V-NV difference scores, we thought it likely that one (or more) of these three may be at risk in terms of their mathematics and would be likely to identify the Severe Mathematical underachiever(s) we knew to be located in this class of children. Even at this stage we felt that the boy would most likely be ruled out since we suspected him of lack of co-operation in the one-to-one testing situation. We also found that one of the girls was frequently absent from school with chest infections, which had been a problem throughout her school life, and could account for a poor Mathematics performance.

At this stage we thought that one of the two girls was the 'severe' underachiever, but were unable to choose unequivocally between them. On one hand, one had missed school frequently and may have got behind through missed work, less familiarity with the material, etc., and would clearly be the favourite on 'conventional' explanations. On the other hand, the other girl also had a very large Nonverbal deficit and was slightly unsteady walking backwards, and did not have a ready 'conventional' explanation for these test results.

There was some additional confirmatory evidence for these positions; this concerned the scores on the AH3 test. (The use of this test will be discussed later). The boy had the highest total score of the whole class with a very strong score on numerical material. The two girls had fairly high total scores, with depressed scores on the numerical section, that of the frequent absentee being especially noteworthy.

We therefore decided to see all three children again and to ask them to explain their solutions of the Matrices problems. We expected that the boy would have no difficulty in correcting most of his previous errors, and that at least one of the girls would be unable to greatly improve her performance, but that also the nature of her errors would be indicative of an underlying difficulty relevant to mathematical performance.

IDENTIFICATION OF THE MATHEMATICAL UNDERACHIEVER(S)

The boy correctly solved all but one of the Matrices problems when we asked him to explain his solutions. The one mistake he made on this occasion was to overlook one dimension (position of the symbol in the square). The ease with which he solved the problems was apparent to both examiners present.

The girl who suffered from frequent absences was able to correct two of the mistakes she had made at the original testing session. She tended to omit dimensions from the more difficult Matrices and frequently tried to use inappropriate methods, e.g. "It must be this symbol because there is only one other like it in the whole design". These errors are similar to those of younger children, and may be due in this case to lack of experience. She certainly showed flexibility in the methods she employed. Nevertheless, operating at a level inadequate to her age and Verbal ability, would certainly imply some degree of underachievement.

We then asked her to do a few questions from NFER's Basic Maths Test F-G, working aloud. This revealed many weaknesses in mathematical performance, both in familiarity with concepts and understanding. Basic addition, subtraction and multiplication tables were good, but division and fractions were weak. These are illustrated by the following extracts from a transcript of her attempts at these questions.

<u>Q</u> : $4 \div 5 \times 10$	<u>Ans</u> : "4 divided by 5 is $1\frac{1}{5}$ ... times 10 is $10\frac{1}{5}$, I think".
<u>Q</u> : $8 \times 5 \div\ = 4$	<u>Ans</u> : "8 times 5 is 40 ... divided by something is 4. By 10".
<u>Q</u> : Insert $\begin{smallmatrix}<\\=\\>\end{smallmatrix}$ as appropriate in $15 - 9$ .. $9 - 15$	<u>Ans</u> : "15 take away 9 is 6. 9 take away 15 ... You can't do it. It leaves nothing".
<u>Q</u> : Insert $\begin{smallmatrix}<\\=\\>\end{smallmatrix}$ as appropriate in $8 \div 15$ ... $15 \div 8$	<u>Ans</u> : "8 divided by 15 ... you can't do it. 15 divided by 8 is 1 and 7 over".
	She then inserted < correctly.

On the other hand, her strategies for tackling questions were appropriate in general. Two other weaknesses which showed up in this session were inability to draw mirror images of complex symbols, and <u>some</u> difficulty in generalising a well-known procedure (addition and subtraction) to new material (binary arithmetic using shapes instead of numbers), but this difficulty was only apparent with the more complicated examples.

We considered that this pattern of results was consistent with a lack of facility in using numbers which may be due to her absences from school. A glance back through the school register, and confirmation from the girl herself, revealed a very poor attendance record. The girl said that her absences from school were spent reading books rather than practicing with numbers; this would in part explain her good scores on AH3-V and Similarities and her poor score on AH3-N (in which speed was a vital component).

However, although she was clearly underachieving in Mathematics, we thought her attempts at Basic Mathematics F-G revealed a moderate rather than a severe degree of underachievement; and we reserved judgement on the identity of the severe underachiever until we had seen the other girl with a large Matrices-Similarities score discrepancy.

The latter was also able to improve on her previous performance on the Matrices test when asked to justify her answers. But she often failed to use all the components available although she could indicate the different features of the components. She recognised the more complex examples as such but still used only two rows or just the diagonal squares of the Matrix to complete the example.

This seemed to indicate an inability to see the relevance of available information to the solution of the problem, and combined with her first attempt at the Matrices test which had revealed inappropriate perseveration of method, suggested that she would have difficulties in complex Mathematical problem-solving, both in selecting appropriate strategies and appropriate information.

The similarity between this case and some of our sixth-form sample with large V-NV differences suggested that this girl would be underachieving in Mathematics, possibly severely so.

When asked to attempt some questions from NFER's Basic Maths Test F-G, three things became apparent. First (a) that tables and number facts were well-known; second (b) that some concepts were not familiar, and others were not recognised or not seen as relevant; third (c) that there was a tendency to persevere at a method and use stereotyped methods. This latter had also been seen in her first attempt at the Matrices test. These observations are illustrated by the following examples from her attempt at this Maths test.

(a)	Q : 4 ÷ 5 x 10	Ans : 4 ÷ 5 = 0.8 0.8 x 10 = 8
		Note This question was the one most likely to be failed due to arithmetical errors by our under-achieving samples.

No purely arithmetical errors were made on any question.

(b)	Q : Insert $\lesseqgtr$ as appropriate in 15 - 9 ... 9 - 15.	Ans : "15 minus 9 is 6. Equals... No it isn't. What am I saying? ... 9 minus 15 is ... something ... I don't know what it is".
	Q : Underline the two equivalent to $^3/_{10}$: 3%, 30%, 3.0, 0.3, 0.03.	Ans : "30% and ... 0.03 ... I don't know ... The tens columns and hundreds columns seem confused".

In questions such as finding the two different operations from +, -, x, ÷ such that 5 .. 2 .. 3 = 6, she constantly failed to use the facts that, in integer arithmetic, + and x increase the result, while - and ÷ decrease it.

(c)	Q : Insert $\lesseqgtr$ as appropriate in 8 ÷ 15 .. 15 ÷ 8	Ans : 8 ÷ 15 = 0.53, 15 ÷ 8 = 1.875 (performed as long division sums).

Q : □, ◇, Δ, O stand for +, -, x, ÷ in some order. If 5□2◇3 = 6 and 6 Δ 3 O 2 = 9 find what each stands for.

Ans : She used trial and error to obtain 5 - 2 + 3 = 6. But she then failed to realise that Δ and O must be X and ÷ in some order. She began by trying Δ = +.

Q : If Δ + Δ = □ and □ + □ = * and * + * = O, how many Δs are there in a O?

```
         * Δ                O  □Δ
Add :  O   Δ    Subtract    *   Δ
       -----               ------
```

Ans : Correctly said 8. Then in order to perform the addition and subtraction she first converted everything into triangles and then converted the answers back. The addition was performed correctly, but the subtraction was left as :

```
 8̸7  1₀     7̸1   11
O    o      □    Δ
     *⁴          Δ¹
-------------------
7    6      1    0

(* □ Δ)(□□□)Δ
```

This pattern of arithmetical competences combined with an inflexible, stereotyped approach to mathematical problems (seen here, for example, in her meticulous long division of 8 ÷ 15 and 15 ÷ 8 to find which was the larger - in contrast to some of our less able 'Nonverbal' sample children who said 8 ÷ 15 is less than 1 but 15 ÷ 8 is greater than 1), was fairly typical of our mathematical underachievers who had large Matrices/Similarities differences, with depressed scores on Matrices. As we saw in Chapter V, this pattern was associated, particularly in our sixth-formers, with severe mathematical underachievement. This girl's performance, therefore, confirmed our opinion that she was likely to be the severe underachiever in Mathematics. This, in fact, was the case.

DISCUSSION

We have seen that, apart from the two mathematical underachievers, our 'normal' class compared favourably with our two samples of mathematical underachievers, as regards all three 'significant areas of functioning'. That is, there were lower incidence rates of anomalous (particularly crossed) laterality, lower incidence rates of very poor Digit Span scores, and lower incidence rates of large discrepancies between Similarities and Matrices scores. These comparisons have not been emphasised here, since they were commented on in the earlier chapters when the underachieving groups were compared with NCDS and BAS norms. However, these findings do suggest that the links between mathematical underachievement and these 'significant areas of functioning' have some validity, and give some further support to the findings of our study.

The 'severe underachiever', in common with some of those identified in the NCDS and with many of our case study children, was not achieving 'below grade level'. She was not 'backward' at Mathematics, being at least average, but her Mathematical achievement was very low compared with other areas and with her measured ability.

The underachievement of this girl, and of other case-study subjects who had large V-NV differences of the type described here, was not due to the mechanics of Mathematics (for mathematical facts and common algorithms were usually mastered) but to thinking processes behind it (i.e. the selection of efficient strategies and choosing relevant information were not very good, and there was a tendency to apply algorithms to the data in a very stereotyped manner with no clear overview of the problem and its mathematical setting). This explains why our ability tests, rather than the AH3 test (which contains a numerical section) diagnosed the severe underachievement (see later).

Our test battery in fact identified two likely underachievers; the one who gave rise to the choice of this particular class of children (see page 394 of this Chapter), and one who had missed a good deal of school through illness. The mathematical difficulties of the latter were consistent with lack of practice and failure to master concepts sequentially; speed was therefore a major factor in her performance on AH3-N (see later).

Data from the project on achievements and attitudes which was used in the choice of this particular class of children, showed that 23 of the 26 children in this class had both VR and Maths. test data (recorded in that project) and that relative to the population of 2,000 local comprehensive school children from which they were drawn they were underachieving in Mathematics by an average of approximately ½ s.d. Allowing for this, our 'severe underachiever' was still underachieving by a very large margin. This was, in fact, confirmed by her scores the following year, when the same project found that she was still underachieving.

Unfortunately, we have no early histories for either of the two underachievers found in this study of a 'normal' class. Analysis of the NCDS data suggested that for underachievers with large V-NV differences, degree of underachievement and number of abnormal pregnancy and birth factors ('risk' factors) tend to increase together (see Chapter VIII). Moreover, for girls, there was also a suggestion that long illnesses were related to perinatal factors (see review of May's dissertation in Chapter III).

We end this Chapter with a note on the use of AH3 tests in our test battery. Our test battery was based on the hypothesis that some mathematical underachievement has neurological origins, and was designed to identify cases in which neurological factors might be implicated.

There are, of course, cases of mathematical underachievement which are free of any neurological factors, and these may not be picked up by our test battery; but they would be identified by mathematics attainment tests, such as those used to identify the severe underachiever in this present study, and also by AH3, which the Manual describes as a diagnostic test. Thus, use of both AH3 and our 'neurological' test battery should give some indication of whether or not neurological factors might be implicated in any cases of underachievement found.

As we pointed out in the discussion of our choice of tests for our test battery, AH3 is a test of reasoning. It is therefore related to general ability, and we have in fact used it as an indication of general ability level. However, it also consists of three types of material, and although similar types of reasoning (i.e. analogies, completion of series, odd man out etc.) are tested in the three sections, for a given child there are variations in score between these sections which depend on the relative familiarity and facility in handling the three types of material. Now it is true that, in general, the mathematical underachievers in our case studies tended to score lowest on the numerical material section (as a glance at Tables 4.2, 5.2 and 9.1 will confirm). But, Tables 4.2 and 5.2 show that not all underachievers had lower scores on numerical material, and, moreover, lower scores on numerical material did not always imply severe underachievement (Table 9.1). Moreover, this test did not pick out the severe underachiever ; although it did, quite decidedly, indicate the milder case.

Because AH3 was designed to be a test of reasoning, the actual arithmetic required was fairly simple, and a low score on the AH3-N section generally results from lack of facility in handling numbers, which leads to a very slow rate of working, rather than sheer inability to do arithmetic. The underlying causes could be any of those hypothesised in Chapter II. This applies to the use of any other achievement tests. Where number facts are well-known (as in some of our sixth-formers and the severe underachiever in this Chapter) the depression of the score on numerical material is not so great. Thus AH3 would tend to diagnose only certain types of underachievement, and give no clue as to underlying causes.

In fact, our test battery picked out the two underachievers without the use of AH3 as a diagnostic instrument (except as confirmation of high ability).

It is significant for our study of dyscalculia that a test battery based on the concept of neurological involvement in (some) mathematical underachievement was successful in identifying the two underachievers ; when a diagnostic (see AH3-Manual) test with a specific mathematical content only unequivocally identified the less severe case.

CHAPTER X

CONCLUSION

We began this research with a cautious opinion, based on the literature, that it would be worthwhile to investigate the concept of dyscalculia, defined (after Kosc) as underachievement in Mathematics due to neurological impairment. Worthwhile in three senses: first that it would acknowledge that there may be children who are underachieving in Mathematics despite adequate intelligence, teaching, motivation and effort, and that they should have their difficulties investigated instead of being simply labelled "lazy", "careless" or "just unable to do Mathematics". Secondly that we should look for some evidence of its existence, even if such evidence is indirect (see next paragraph), and thirdly that a knowledge of any underlying causes of such underachievement may lead to remediation or compensation strategies to help these children to do better in Mathematics.

We acknowledged from the first that we should find no absolute or direct proof that any of the children investigated were underachieving in Mathematics due to neurological impairment. For to do so, one would have to show (a) that the child did have a neurological impairment, (b) that social, emotional, educational, or motivational factors were definitely <u>not</u> responsible for the underachievement and (c) exactly how the neurological impairment led to the mathematical performance that produced the underachievement. At present the state of knowledge and the techniques of neurological and behavioural science are not sufficiently advanced to make any of these fully possible, except for obvious cases of (a). On the other hand, we also acknowledged that the possibility of neurological impairment as an underlying cause could not be absolutely disproved by absence of detected neurological impairment, presence of social, emotional, adverse educational or poor motivational factors, or lack of knowledge of the brain mechanisms responsible for a given mathematical performance, either singly or collectively. (Indeed, as we saw in the Introduction, we might expect all three in a typical dyscalculic).

Our strategy therefore, has of necessity been based on making inferences from indirect evidence. Starting with groups of children who were underachieving in Mathematics, we have looked at a large number of social, educational, emotional and ability and achievement variables in a very large-scale study and at a smaller range of variables in case studies of local schoolchildren. Both of these groups of children yielded a subset who were underachieving in mathematics and whose laterality preferences were deviant. The connection between laterality preferences and achievement variables in the two groups and in the literature were explored in Chapter VI. The case study group also suggested connections between Mathematics underachievement and short-term memory. In the absence of memory data in the large scale study, the short-term memory factor was investigated in the case study group and in the literature in Chapter VII. The most striking feature of our case studies of sixth-formers was the prevalence of large Verbal-Nonverbal differences in ability.

This Verbal-Nonverbal difference factor in underachievement was explored through both groups of children and the literature in Chapter VII.

Our investigations thus led us to three factors: short-term memory, large Verbal-Nonverbal differences in ability, and deviant (particularly "crossed") laterality, which do appear to be linked with Mathematics underachievement, and which seem to be independent of social, emotional, educational, and motivational factors. We have provided arguments and evidence to show that each of these factors can be linked to possible neurological impairment and also to Mathematics difficulties.

In an attempt to provide some validation of the short-term memory factor, we found from the literature that poor short-term memory may be acquired due to known neurological impairment, sometimes with no obvious loss of long-term memory, and may be a concommitant of low ability due to perinatal brain injury. We produced some validatory evidence from the follow-up case studies which showed that memory factors played a part in some poor Mathematics performance; in particular in two case studies where Mathematical performance was studied in great detail. The literature provided some theoretical ideas on the mechanisms involved. In the one case study subject with poor short-term memory for whom we were able to obtain early history, we found a significant neurological event in the first week after birth, namely 24-hour fits.

The second "linking factor", large Verbal-Nonverbal discrepancies in ability, was also recorded in the literature as being acquired due to known neurological impairment (so much so that some neurologists use very large V-NV differences as indicative of brain damage, and the direction of the difference as indicative of the hemisphere involved), and as following known perinatal damage. We also found evidence in the literature for links between specific regions of the brain and specific Mathematical areas; for example the links between the right hemisphere and spatial visualization, and between an area of the left hemisphere adjacent to the "language area" and arithmetic. Very tentatively, from our case studies of children actually doing Mathematics, we detect a tendency for smaller Verbal scores to be linked to difficulties in comprehension, and for smaller Nonverbal scores to difficulties in strategy selection.

The third "linking factor", deviant laterality, has proved the most elusive to explain as a neurological factor. However, the literature gives us many cases of change of handedness with neurological impairment in adulthood, an increased incidence of left-handedness after left-hemisphere perinatal brain damage, and a history of high incidence rates of left-handedness and cross-laterality in clinical populations of severe learning-disabled patients. Handedness does appear to be a neurological variable in the sense that there is a link between language representation in the brain (left-hemisphere, right hemisphere, or bilateral) and preferred hand. There are also theories linking language representation in the brain and academic achievement (mainly in language areas of achievement).

However, the most striking laterality deviance in our case studies was not left-handedness but cross-laterality of hand and eye (as was also the case in Orton's clinical dyslexic cases). There is some slight evidence from our large-scale study that in severe specific Mathematics underachievement, cross-laterality tends to occur with poor coordination, perinatal difficulties and extreme physical size variables (the latter possibly linked with perinatal problems).

On the basis of this research, the evidence suggests that there is no single syndrome of dyscalculia. However, we feel that the evidence presented is sufficient for neurological impairment to be taken seriously as a cause of mathematical underachievement. In these circumstances we feel that there are some grounds for using the term dyscalculia as a blanket label to help alert people to this form of mathematical underachievement. If this is done, however, its global nature must be clearly appreciated, but this is not always easy to communicate. Evidence from the use of similar global psychological terms such as dyslexia has not always been encouraging, and at this stage we would recommend that further research be undertaken to clarify the types of mathematical performance which may be affected by neurological impairment before suggesting that the concept is a profitable one for everyday use. As yet it is not a practical concept for use in schools generally, but it is one which deserves further research and one which teachers should be aware of. The limited evidence reported here suggests that it should be considered as a possibility in cases of serious underachievement, along with social, educational, emotional and motivational causes;

particularly in cases where underachievement has led to frustration, anxiety or 'opting out'. Our identification of "linking factors" may be a first step towards the identification of dyscalculics as a distinct group of underachievers.

However, if dyscalculia does exist in the sense in which we have defined it, our research suggests that, like dyslexia, dyscalculia is not a unitary concept. This reinforces our definition, which leads us to expect that different types of neurological impairment would be expected to lead to different types of mathematical difficulty. Moreover, the interaction of neurological impairment with the known plasticity of the infant brain and the compensation strategies of different individuals could also lead to situations where similar impairments would result in different disability profiles, especially in terms of severity. Here again, the presence of different "linking factors" may be a crude basis for differentiating dyscalculic types and their specific associated difficulties.

Even further away at present is any well-founded remediation or compensation strategy for dyscalculia, and without these the use of the concept within schools would be counter-productive. Clearly, however, results of research in support of those presented here, together with intensive studies of specific difficulties and errors, could supply pointers towards useful intervention. An evaluation of interventions based on theoretical models of dyscalculic types, compared with traditional remediation methods, based mainly on theories of slow learners, could then provide additional support for the concept of dyscalculia and its usefulness. For though "neurological causes" are theoretically important, the concept of dyscalculia is only useful if it (i) makes educators aware of the large difference between "lazy" or "careless" and learning-disabled, i.e. serves to differentiate among causes, and (ii) provides a basis for more effective remediation or compensation strategies. This should be the aim of further studies which may corroborate and extend our findings.