LATERALITY, READING AND ABILITY IN CHILDREN

Thesis submitted for the degree of
Doctor of Philosophy
at the University of Leicester

by

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January 1990
Acknowledgements

I wish to acknowledge that the work for this thesis was funded by a grant to Dr. M.E. Annett from the Medical Research Council.

The completion of this thesis has depended on a great number of people. I especially want to thank Ann Colley, her assistance and guidance were invaluable. Without her support and constructive comments I would have been lost. Special thanks are also due to Elizabeth Noon who has been so generous with her time and her confidence boosting counselling sessions over the past few months.

Special thanks must go to the children and teachers of the schools who participated in this study. Without their help and co-operation the work could not have been completed.

I am also grateful to John Ashworth who drew the figures at such short notice, Carol Sourbutts who helped type the tables, and Rob Hemmings who with patience beyond the call of duty, helped with the printing.

The support of May Awaida, Sue Barraclough, Lyn Allsopp and my sister Geraldine has also been much appreciated.

Last and by no means least, a very special thanks to Ken, Richard and Scott for their unconditional support throughout the past four years. This thesis is for you.
Margaret Manning

Laterality, Reading and Ability in children

Abstract

Various hypotheses derived from Annett's (1972; 1985) genetic theory of handedness are experimentally tested. Results from the first investigation show that excessive bias in favour of right handedness is due to a weakness in left rather than superiority of right hand skill, and is associated with poor nonverbal reasoning ability. A second investigation indicated that risks to reading problems were increased in children with either too little or too much bias in favour of dextrality. A further three studies investigated patterns of ability and disability at both laterality extremes. It was found that language deficits were more frequent in children reduced in bias towards the right hand. An attempt to find a task which those at the dextral tail of the laterality distribution were worse at than those at the sinistral tail met with inconclusive results. The experimental findings are, in general compatible with Annett's hypothesis of a human balanced polymorphism with heterozygote advantage for ability.
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Preface

Early in 1986, the time when this thesis was begun, my knowledge of and about human laterality was decidedly limited. Not until six months into the research and five chapters of Annett's book *Left, Right, Hand and Brain: The Right Shift Theory* was I even aware of the variability in human hand skill or its potential importance to our understanding of individual differences for ability.

From this time onwards my interest was in finding explanations that could account both for the observed human bias towards right-handedness, and the stable prevalence of left-handedness in normal populations. In the search for answers to such questions I discovered several theories, each with empirical support, that could in different ways offer answers for the clinical samples, but none that were convincing enough, for me at least, for normal populations. For instance, in spite of an unbroken history dating back some 5000 years, the left-hander was, and still is, often referred to as defective or pathological in some special way, rather than just being different.

The founder of modern day research into possible biological mechanisms of lateralization is almost certainly Norman Geschwind. Geschwind and associates (see for example 1982; 1984; 1985) postulated that observed asymmetries of an area known as the planum temporale, which is part of Wernicke's speech area, might determine left hemisphere speech development for the majority. The important distinction was made
between the individual for whom pathological left-hemisphere
development determined nonright-handedness and accounted for increased
risk to developmental disorders such as dyslexia and speech
impairments, for example stuttering, and the individual with normal
brain development, no close left-handed relatives and
right-handedness. The progression of Geschwind's work has, from the
earliest days, proposed an association between early developmental
testosterone levels, variations in patterns of cerebral specialization
and handedness. The work of Geschwind in the last decade thus heralded
a return to the pathological versus normal brain development style of
investigation, so preferred by early investigators such as Broca and
Wernicke.

A radical departure from the 'pathology of sinistrality' viewpoint was
that of Annett's Right Shift theory. She suggests that learning
difficulties are just as likely in the strongly right-handed as in the
left-hander because they both represent the extremes of the laterality
continuum. Annett proposes that a genetic mechanism in the form of a
single gene, influences left hemisphere speech development and an
increased likelihood of dextrality, but at the same time carries risks
for right hemisphere handicap. If as Annett has proposed left-, mixed-
and right-handedness are all part of normal human variability of both
hand and brain organization, then empirical answers to my original
questions were possible.

One of the major criticisms which has dogged much of the work in the
area of individual differences has been the highly select nature of the
samples being reported upon. Typically, the subjects employed in such instances are not representative of normal populations either for ability or handedness, the result being a failure to detect any significant effects for laterality. Annett suggests that this tradition, of attempting to extrapolate from highly select groups to normal populations, does not allow a sensitive enough measure of laterality and its implications for ability. Given that normal populations include individuals outside the range of handedness differences reported in special groups such as undergraduates and clinic referrals, knowledge of the whole spectrum of individual differences of both hand and ability in a representative, unselected population is essential.

The aim of the investigations to be reported upon in the following pages is to examine further the relationship between handedness and human intellect; specifically within a large unselected population of school children in order to allow a direct comparison with studies reported in the literature which have employed highly select samples. Several hypotheses derived from Annett's (1972; 1985) Right Shift Theory will be experimentally tested.

The knowledge base for this thesis is broad therefore the first chapter will review relevant literature from several areas including cerebral dominance, specialization of function, handedness and intellectual abilities.
CHAPTER ONE

Review of relevant literature

1.1 Population differences in patterns of brain organization and handedness

(a) Studies in the literature on the cerebral dominance of left- and right-handers

The study of possible relationships between handedness and brain organisation has attracted academic interest for over 120 years. At the turn of the century interest was at its height: In 1868, Hughlings-Jackson, following in the footsteps of such figures as Wernicke and Broca, published Observations on the Physiology of Language. The aim of this work, which can justifiably claim to be one of the first to examine speech loss in left-handed patients with brain damage to the right cerebral hemisphere, was to draw attention to the possibility that both hemispheres were capable of directing speech.

From this time to the present day neuropsychologists have debated whether the highly lateralised nature of the human brain in the majority, i.e. right handedness is sufficient evidence that the brain organisation of the minority, i.e. left-handers, is abnormal. One of the main aims of contemporary research has been to define with greater accuracy the association between handedness and unilateral organisation for speech. Inevitably the main focus of attention in the study of individual differences has been to account for the prevalence of sinistrality in terms of the way in which speech specialization might differ for left-handers, or right-handers with close left-handed
The possibility that left hemisphere language lateralization might also be the basis of structural asymmetries between the two sides of the brain, has also been noted by several writers. Geschwind & Levitsky (1968) for example, suggested that: '...the planum temporale, asymmetry of this zone may account for the predominant localization of speech to the left hemisphere in the majority of humans' (page 2, cited in Geschwind & Galaburda, 1987). These findings have been endorsed by several writers over the years. Wada, Clarke & Hamm (1975), Witelson & Pallie (1973), Teszner et al (1972, cited in Geschwind & Galaburda, 1985), have all noted that, in general, the left planum temporale is larger than the right and implicated in language functions. However, as Geschwind & Galaburda (1985) point out, the effect of atypical functional or structural asymmetry upon an individual's later behaviour is a matter of considerable debate.

Two opposing views can be seen to exist. The 'Geschwind Hypothesis' proposes that excessive testosterone activity during early fetal life acts by slowing down the growth of parts of the left side of the brain. It thereby weakens left-hemisphere predominance in those regions specific to handedness and language and at the same time facilitates development of adjacent cortical areas and equivalent sites in the right hemisphere, resulting in degrees of differences away from typical left cerebral dominance. Several points arise from such a
hypothesis: 1) that for some individuals their right hemisphere will be a mirror image of their left; 2) that the slowing down of the left hemisphere will more often occur in men than women increasing bilateral organisation of cognitive functions, and following from this, 3) that atypical dominance (pathology) is associated with, or causes, learning deficits or superior talent. The argument being that for a few individuals, their intellectual superiority in so-called right hemisphere tasks (visuo-spatial) is directly attributable to a movement away from the typical left hemisphere lateralization for speech (and larger planum temporale), towards increasing structural symmetry and bilateral or right hemisphere dominance. The opposing view is presented by Annett (1972; 1985) who considers such instances of disturbances to the left hemisphere and associated intellectual deficit or talent, as isolated 'exceptions to the rule', and in no way a cause of individual differences.

Annett has strongly opposed explanations which rely on pathology, and introduced a genetic theory of handedness, which is unique in that its main characteristic depends on an assumption that human variability in patterns of brain organization and handedness is normal, and genetic in origin. She argues that left-handedness as a cue to pathological origins has emerged as a result of asking the wrong questions about lateral asymmetries and their implications for ability. Instead of "Why are so few people left-handed?", investigators have typically asked "Why are so many of us right-handed?". She argues that human populations are not made up of discrete groups of left- or right-handers, but instead represent a continuum of differences in
left hemisphere/right hand bias, from left- to mixed- to strong dextrality.

Clearly, Annett's views conflict with those of the pathology theorists over this issue of whether clinical cases (i.e. dyslexics who present written language disorders) with known brain damage, are relevant to our understanding of individual differences in the development of asymmetries of hand and brain in normal populations. The Right Shift (RS) Theory suggests that the mechanism by which left hemisphere lateralization for language is assured, together with its association with right-hand bias for the majority is double-edged, in that any left hemisphere gain is only through right hemisphere loss. Specifically, Annett argues that the persistence and stability of sinistrality among human populations is not because of some highly select advantage but rather, because of the significant risks to loss of right hemisphere functional efficiency in individuals who overdepend on the left hemisphere and right hand. The left-hander's role, Annett argues (more likely rs-- genotypes), is to prevent such handicaps from spreading throughout the population. The theory contains the essential proposition that for the majority of children with learning difficulties, the nature of their problems are not pathological but reflect the extremes of the distribution of normal biological differences.

In most laterality research however, the pathology hypothesis either implicitly or explicitly, has prevailed, typically arguing that behavioural differences observed in some left- and mixed-handers when
compared to right-handers is abnormal (Geschwind & Behan, 1982; Taylor, 1974; Gordon, 1980; 1983; Maccoby & Jacklin, 1974; Levy, 1974; Benbow, 1986). In an American study two groups, one very strongly left-handed and the other strongly right-handed were assessed for personal and family histories of learning disorders. The strongly left-handed group were found to be significantly more likely to report learning disorders, the authors stating that: "The rate of dyslexia was fifteen times as high in the strong left-handers as in the strong right-handers, and stuttering was five times as common in the left-handers" (page 84, Geschwind & Galaburda, 1987). Similarly in a study by Oldfield (1971) subjects reporting even mild deviations from strong right hand preference were shown to be at greater risk of dyslexia (9% frequency as against 3% in right-handers). Thus there is a history of learning disorder classification made on the basis of the belief that "the influences that favour nonright-handedness", as Geschwind & Galaburda put it, lead to an elevated frequency of reading problems. Such opinions, it should be noted have prevailed even in the absence of any neurological evidence of brain damage.

Two issues arise from this discussion: is the link between sinistrality and pathology intended to hold for all left-handers or only a few and, are all left-handers right brained for speech and all right brained speakers left-handed? These points require empirical investigation for two reasons: whether such differences are part of normal, human variation or simply a reflection of pathology in special cases, and secondly, the implications for ability - does sinistrality lead to an increase or decrease in talent or disability? - and a
further question, why should it have this effect?

One of the first attempts at considering some of the above questions, was that of Zangwill (1967). In an analysis of five large surveys of patients with speech loss, Zangwill noted the similar frequency of risk of dysphasia (speech impairment caused by damage to the central nervous system) between right handers and left handers with lesions in the left hemisphere (60% versus 55%, right and left handers respectively). There was, however, an important difference in risk of dysphasia found between left- and right-handers with right sided lesions - 2% in right-handers and 29% in left-handers (Annett, 1985). Similarly, Newcombe & Ratcliff (1973) noted that among some normal, (presumably previously healthy) war wounded men there was a loss of speech following unilateral right brain damage. Thus while evidence supports an association between brainedness and handedness in that left hemisphere/right hand bias is the most frequent, there are clearly exceptions to this rule.

Awareness of the issues outlined above are by no means a recent preoccupation for psychologists. Orton (1937) for instance, recording the results of assessments of handedness, eyedness and footedness on children referred for developmental language problems, proposed that incomplete cerebral dominance was the cause of learning deficiency. His sample included many children lacking consistent right sided bias but who instead showed varying degrees of bias to each side. This 'motor-intergrading' as Orton called it was believed to carry risks for confusions between information laid down in each side of the brain and
to be causally associated with learning difficulties.

The empirical question, however, remains as to whether atypical asymmetries reported in clinic populations tell us anything worthwhile about normal, population variance of hand and brain dominance. In answer to the points made earlier (page 8) there seems some justification in the conclusion that there are some left-handers for whom the left hemisphere is dominant for speech and some right-brained speakers who are not left-handed. Further, the suggestion of the findings considered above and the weight of considered evidence is that atypical asymmetries are often associated with impaired language ability. The question as to why this should be remains unresolved although several hypotheses, including pathology, have been advanced. In order to present empirical and directly testable hypotheses from Annett's attempt at a paradigm shift, the Right Shift (RS) Theory of handedness must be more closely examined. The view, that the advantages of bias to the left hemisphere for speech is bought at some cost to right hemisphere function, is clearly in contrast to the "Geschwind Hypothesis" view that the study of laterality should begin with a consideration that early left hemisphere pathology determines left- and mixed-handedness and ability.

(b) Annett's (1972; 1985) Genetic Theory of Handedness

Unlike previous theorists Annett supplied a theoretical framework to support a genetic hypothesis to account for a fall off in efficiency of right rather than left hemisphere function. This was done by reference to non human data: "In mice, a mutant strain has been studied in which
right and left arrangements of the viscera (situs solitus and situs inversus) each occurs with 50% probability; this suggests that the arrangement typical in vertebrates, including man, is genetically determined but that when the gene inducing this pattern is absent, the arrangement depends on chance" (page 180, Annett, 1985).

While several animal species have been observed to be about equally divided between left and right preferences, and others present 25, 50, 25% proportions of left, mixed and right preferences, it is only man who shows a clear species bias favouring the right hand. It was from such human and nonhuman data that Annett inferred there could be an underlying continuum of between hand difference (L-R) in manual dexterity which is moved to the right in humans in comparison with other species. Annett has subsequently demonstrated in several large samples of undergraduates that individual differences in L-R manual dexterity was unimodal, continuous and normally distributed but shifted, in its entirety to the right of the mean of the nonhuman species of '0' or no difference. Clearly, two fundamental questions arise. Firstly, what is the origin of the normal distribution, common to both man and some nonhuman species, and secondly, why the human bias towards dextrality?

The basis of the bell-shaped curve, according to Annett is non-genetic and a reflection of random, accidental differences in the in utero development of the two sides of the body, brain and nervous system. While the majority are not weighted in bias to either side (symmetry) those that are, (asymmetry) are just as likely to be to the left as to
the right. In contrast, the nature of the factor which induces the human shift to the right is proposed to depend on a genetic mechanism, a mechanism which sets man and some animal species apart. Intuitively, any explanation has to rest on whatever is present in humans but absent in animals - the most obvious being speech. Annett suggests that in addition to the variability due to genetics (the random combination of genes) there is a major source of variability which produces the normal distribution as distinct from the human shift to the right. This source, according to Annett, is a single gene, the rs+, present throughout the population in combination with chance (which is always there) prompting the most efficient organization of speech in the left side of the brain and incidentally moving the mean of no difference between the sides (probability) towards a bias favouring right-handedness.

This is not to say that the rs+ gene causes speech, only that its presence increases the probability of superior efficiency of sensorimotor control of the speech apparatus by making the left hemisphere dominant. In principle, the most important role of the rs+ gene is in making sure that both perception and production of language is in the same cerebral hemisphere. Clearly, there would seem to be positive human advantage to having what are considered complex functions of hearing and vocalization in the same side of the brain rather than divided between the two hemispheres. Thus, the often referred to factor of pathological lateralization of language may in fact simply be normal, random variation in the development of the two sides of the body.
The normal distribution merely accounts for error variance across a
general population. What is more interesting is the 'movement' of the
means which underly the continuous variance which can be measured by
the difference between right + mixed handers - left-handers. Such a
calculation allows thresholds to be drawn for right-, mixed- and
left-handers. The degree of 'shift' allows us to estimate the expected
proportion of rs--, rs+ and rs++ in each handedness group.

Investigation of the theory continues with an examination of the
implications for ability of having too little or too much of the
hypothesised 'right shift' factor. For about 20% of the population the
rs+ gene is considered absent, (the rs-- genotypes at the sinistral
tail of the handedness continuum), these individuals gain none of the
extra benefits associated with the rs+ gene for language development,
are at greater risk for speech related difficulties but risk no loss of
right hemisphere handicap (possibly the 'classic' dyslexic who is a
poor reader but good at mathematics). This does not presuppose that
all such individuals will necessarily develop such problems, nor that
those who do are pathological in kind, only that the element of risk
changes.

30% have too much of the factor and are so strongly biased to the left
hemisphere as to have clumsy left hands, and significant handicap to
right hemisphere visuo-spatial and mathematical abilities (at the
dextral extreme of the handedness continuum, more likely rs++
Thus the hypothesis of a genetic balanced polymorphism due to heterozygote advantage for ability is essential to the theory that the advantages of bias to the left hemisphere for speech in the majority is bought at some cost to right hemisphere functions (believed to be mainly visuo-spatial or nonverbal). The most frequent population genotype is the rs+ (when deduced from incidences of right hemisphere speech), therefore the majority of the population have the most to gain from the presence of a single copy of the rs+ gene for language development and the least to lose in terms of right hemisphere handicap. Clearly, the presence of the homozygote, rs− genotype, ensures that the hypothesized risks associated with dextrality do not spread throughout the population, 'balances' the distribution, but at the same time fails to gain the extra boost to language development carried by the majority, the heterozygote rs+ genotype.

These predictions are consistent with the findings of increased reading difficulties in nonright-handers (Geschwind & Galaburda, 1985); poor mathematical ability in strong dextrals (Annett & Kilshaw, 1982) but inconsistent with results from Levy (1974) and Benbow (1986).

Annett emphatically states that the action of the right shift factor (the rs+ gene) has to be set against a background of chance. Therefore, on the law of probability half of the rs− group will have as their major hemisphere for language the left and be right-handed, as do the majority. However, not all left handers are due to chance alone, some may carry the rs+ factor. The bias to the right, when present, functions as a constant weighting added to this random
variation. Annett's account of the population distribution of
asymmetries of hand and brain with its overlapping distributions is
heavily dependent on the influence of chance as has been indicated, and
therefore makes variability due to hypothesized genotype very difficult
to detect. As a rule rs-- and rs++ genotypes are expected to be at an
increased frequency at left and right extremes of the laterality
continuum while rs+- are expected at an elevated frequency in the
middle of the distribution and less likely at either extreme.

Figure 1.1 summarizes the assumed distributions of the three
genotypes. The x-axis represents between hand differences for actual
hand skill on Annett's peg moving task; this takes the form of a
continuous and unimodal distribution for the population. The peg
moving task involves moving ten wooden dowels, one at a time from one
row of holes to another parallel row as fast as possible, using first
one hand and then the other for between 3 to 5 trials (precise details
of this task are given in Chapter 2, page 70). L=R represents the
point of no difference between the hands; all those to the left are
faster with their left than their right hands, and those to the right
the converse. Those carrying one copy of the rs+ gene (the
heterozygotes rs+- genotypes) have a mean between hand difference at 1
s.d. from the mean of the total population which is at 1 (no
difference, L=R). Two copies (rs++ genotypes) have a distribution mean
of 2 s.d. from L=R, indicating the additive nature of the model with an
absence of any dominance for handedness. The third genotype, those
without any copy of the gene, rs-- genotypes, (about 19% of the
population) depend solely on random, accidental differences in the
FIGURE 1.1  THE RIGHT SHIFT MODEL

Ordinate of the normal frequency curve

0 0.1 0.2 0.3

Left hand faster  L = R  Right hand faster

rs++  rs--  rs++
growth of each side of the body, their mean between hand difference being at 0 (L=R). This 50/50 L-R distribution of the rs-- genotypes is a hypothesis which Annett tested in 1) left x left families for handedness and 2) the dysphasia data for cerebral speech. Referring again to Figure 1.1 (page 16), clearly the distribution of between hand differences for those lacking the genetic influence (the rs+ gene) is believed to be random and showing no particular bias to either side of '0'. Although Annett does not explicitly recognise this point, it would seem more likely in a right-handed world such as ours, that the mean of the differences between the hands in those without any systematic bias, would be more towards the right.

The assumed proportion of the distribution who were rs-, was deduced by comparing the incidence of left-handedness in right- and left-lesioned dysphasics in the population, who had not been selected either for handedness or lesion site. Analysis of Zangwill's dysphasia series showed the incidence of right-brained speakers to be 9.27%. Therefore the proportion of the population assumed to be rs-- was twice this, 18.54%. The incidence of left-handers among left and right lesioned dysphasics allowed an estimation of the extent of shift between the distribution of the rs+ and rs-. Using the normal distribution tables this was calculated as 1.937 z (for a worked example of genotype calculations see Appendix 1). Rather that indicating how good it must be to be dextral, the evidence suggested that while there must be something favourable about having one copy of the rs+ gene (the heterozygotes) as they are the most common, having two copies, the rs++ genotypes, must carry some disadvantage, otherwise they would have
spread throughout the population and eliminated the rs-- genotypes.

The obstacles facing the balanced polymorphism with heterozygote advantage hypothesis was in terms of precise definitions of what it was that the rs++ and rs-- genotypes were expected to be poor at.

Initially, Annett (1978) had suggested the handicaps of the rs++ as right hemisphere visuo-spatial and motor deficits due to an assumed over-dependence on left hemisphere language skills.

This hypothesis was supported, and extended further by the work of Kilshaw & Annett (1983) who found that strong dextrality depended on left-hand weakness and not right-hand strength, and was associated with poor mathematical ability. Following on from these findings it was argued that the action of the rs+ gene was to handicap the right hemisphere at some critical stage of early development. In this context cerebral specialization is only gained as functional efficiency of the right hemisphere diminishes, and not because of its increasing power as proposed by the Geschwind hypothesis. However, Geschwind & Galaburda (1987) partly base their hypothesis on the argument that:
"The earlier development of the right hemisphere implies that it will be less subject to disrupting influences. As a result, we expect that disturbances in cytoarchitectonic structure will be less frequent on the right than on the left" (page 15).

In order to accommodate the RS Theory to the findings of an empirical study by Annett & Kilshaw (1984), in which it was found that excessively dextral children were poor readers as well as lacking in
motor skill, Annett was forced to reconsider, beyond simple right hemisphere/visuo-spatial skills, the specific handicaps assumed to be associated with presence of two copies of the rs+ gene. However, other studies using a different experimental design (hand preferences as opposed to hand skill) have produced findings inconsistent with Annett's results (Harshman, Hampson & Berenbaum, 1983; Benbow & Stanley, 1983; Sheenan & Smith, 1986).

As an explanation for the observed better performance of male left-handers on nonverbal abilities and their poorer performance on language tasks, the "Geschwind Hypothesis", which argued that pathologically high levels of male hormone at a critical period of development plays a role in laterality and associated abilities, has found support from other data. The hypothesis is consistent with findings of a raised prevalence of male left-handers with developmental language problems (Taylor, 1974) left-handers superiority on spatial functions (Gordon, 1980; 1983; Bufferey & Gray, 1972) and the superiority of females on verbal tasks (Maccoby & Jacklin, 1974), but inconsistent with findings reported by Oldfield (1969). This sex difference hypothesis was further advanced by Geschwind & Galaburda (1987) who proposed the term 'pathology of superiority' to describe the proposition that the growth necessary for superior development of some areas of the brain is only gained as a direct response to poorer development of others. In a similar vein, Benbow (1986) came to the conclusion that the left- and mixed-handed male devotes a greater amount of time to attending to visuo-spatial, right hemisphere functions and less to left hemisphere language capacity.
Such results fail to provide evidence which can confirm or disconfirm Annett's theory. In order to disprove the theory groups must be found with asymmetries in the atypical direction or, atypical asymmetry must be reliably shown to be pathological. Data from small samples sizes (typically 16 to 25 subjects) does not provide a full or adequate test of the theory, therefore experimental evidence must be based on large population samples in order to control for the effects of chance.

Annett (1985) proposes that Geschwind's pathology hypothesis of right hemisphere superiority with increases in sinistrality can be empirically compared with the predictions of the RS Theory by assessing the manual dexterity of each hand, on the premise that such a measure allows some insight into the efficiency of the contralateral hemispheres. If the hypothesis that left hemisphere pathology causes intellectual talent is correct, then the skill of the right hand of such children should be significantly weaker than their left hand and, the right hands of intellectually less able children.

Of course, it could also be argued that the extent of deviation away from leftward asymmetry may be crucial in this respect; the strength of movement away from asymmetry the more opportunity there is for functional differences to be beyond the normal range, and be pathological in kind. However, Annett (1985) argues that there is no necessary connection between strength of sinistrality, left hemisphere weakness and nonverbal advantage given that reduced dextrality is a normal, genetic variant.
In combination, both the theories of Geschwind and Annett yield a right hemisphere variability hypothesis of laterality: structural changes in hemisphere identity associated with right hemisphere functional differences which carry implications for human information processing performance. Thus the often cited nondextral deficit and/or talent being attributed to two different factors - pathological increment in right hemisphere proficiency in one, and normal, random variation in the development of both sides of the body and brain, in the other.

As a consequence of the RS theory's emergence as a theory of population asymmetries with implications for ability, very few studies have directly sought to provide a full and proper test of its hypotheses. Apart from the study by Demarest (1982) on 'Manual asymmetry in Guatemalan populations: A cross-cultural test of Annett's right shift theory', little attempt has been made to investigate the implications of hand skill for either verbal or nonverbal ability in large population samples unselected for either handedness or ability.

In order to make any sort of appraisal of Annett's theory it is necessary to consider first the evidence from the experimental neuropsychology tradition relating to cerebral specialization for function and the implications for ability. The validity of such an extrapolation is, of course, questionable, on the grounds that the majority of evidence for a dissociation between visual and verbal function is open to the same criticism previously levelled at the cerebral dominance literature: data is collected from small,
unrepresentative, special groups (clinic samples or undergraduates). However, as the main role of the rs+ gene, according to Annett is to give some boost to language development at some cost to visuo-spatial skills, it is clearly important that these two classes of processing are distinguished.

1.2 The linguistic and nonlinguistic role of left and right cerebral hemispheres

The first obstacle facing the cerebral dominance literature is in terms of a satisfactory definition of normal lateralisation. The classic view of unitary dominance for language and handedness has been questioned in several recent writings concerning a functionally dominant or 'major' hemisphere (Hecaen, 1983; Milner, 1974; Levy, 1974). More recent writers have shown that in reality, functional differences between the two sides of the brain are often not so clearly defined. Unimpaired speech does occur in patients with left cerebral damage. While right-left orientation, speed of writing, speed of hand tapping, independent finger movements, colour identification and complex motor movements, have all at one time or another, also been reported as being impaired in individuals with lesions in the left side of the brain. Farah (1988) has argued that in normal samples there is evidence that the left hemisphere also plays a role in the generation of visual imagery. Importantly, she suggests that "...brain-behaviour mappings probably do not exist, rather the mapping will be between the cognitive processes that underlie behaviour and regions or properties of the brain" (page 54).
Thus, perhaps the more appropriate question might be how little is the functional difference between the two cerebral hemispheres? Why, for the majority, should the left cerebral hemisphere be more able to cope with the extra demands of language when it clearly also has a nonlinguistic role?

(a) Evidence from Dichotic Listening

An explanation for the better recall of information presented to the right ear for normal subjects, draws on the work of Studdert-Kennedy & Shankweiler (1970) who found a right ear advantage (REA) for consonants but not for vowels, while Kimura (1961) reported atypical ear advantage (LEA) for the presentation of digits in neurological patients known to have right hemisphere speech specialization (in that verbal information presented to the left ear was advantaged by right hemisphere processing).

Quite obviously, an important but often neglected consideration of clinical and normal differences such as these is the lack of control over cognitive processing strategies adopted by subjects. Of particular relevance to this point is the case study of R.E. reported by Campbell & Butterworth (1985). She was asked to match a series of heard stimuli with their visual representation, and showed a marked decrement in performance if not allowed to close her eyes in the auditory condition of the experiment, because, as she explained, she could "see the numbers better then" (page 466). Clearly, it would be dangerous to argue that all subjects adopt the same information processing strategies to all classes of stimuli.
(b) Electrical Stimulation Mapping
The evidence from the dichotic listening domain was further supported
by Ojemann & Mateer (1979) who, by using electrical stimulation mapping
of awake patients prior to neurosurgery, found that stimulation of
specific brain sites resulted in temporary but specific disruption of
several functions. A number of language or language-related functions
mapped on to the left cerebral hemisphere and included naming,
completing sentences (reading), short term verbal memory, mimicry and
oral facial movement, and phonemic discrimination. When the same sites
in the right hemisphere were stimulated, no language disturbance or
problems of motor mimicry were apparent. The important point to note
is that both disruption of phoneme recognition and sequences of oral
mimicry were found at the same sites in the left hemisphere.

There are however, limitations on how far one can generalize such
findings to normal populations, the most crucial being that the very
nature of the sample, i.e. their known brain pathology prior to
surgery, raises the possibility that responding was a direct
consequence of their abnormal cerebral organization. Just as important
is the need to consider that dissociations due to brain damage may not
necessarily reflect instances of peculiar behaviour due to cerebral
insult (stroke etc.) but rather as an example of the brain's
adaptiveness in drawing on remaining, normal, intact functions. This
of course, raises the important question of how much of a performance
is abnormal? The scarcity of direct evidence as to real differences
between normal and clinic groups could possibly be overcome if
clinicians used a series of single case studies employing exactly the
same methodology as that used with normal subjects. This would allow not only normal-abnormal comparisons to be made, but would also enable patients who lie within the bounds of normal differences, even on a single measure, to be recognised.

From the range of studies quoted above it is clear that the concept of cerebral dominance, and its implications for ability, has received considerable, well documented, attention in neuropsychology. As noted elsewhere (page 6) Geschwind suggested 'right hemisphere enhancement' as a predictor of left-handers' pathological language performance and enhanced nonverbal skills, while Annett proposed right hemisphere handicap as a fitting explanation for disadvantages in both verbal and nonverbal abilities associated with strong right-handedness (Annett & Kilshaw, 1984). Neither of these explanations can offer a specific prediction for the precise implications for language for the child with early, unilateral lesion to either hemisphere.

So, does early serious neurological insult to either side of the brain result in an absence of speech? Are there qualitative differences in speech between children with right and left sided lesions? What are the implications for intellectual ability? Such questions are crucial to our understanding of the nature and development of cerebral specialization for language.

(c) Development of right hemisphere speech
The evidence is that in general children always develop speech regardless of whether lesions are to the left or the right cerebral
hemisphere, and even in extreme cases when the left side of the brain has been removed entirely (hemispherectomy). Therefore clearly, the important question is not whether either hemisphere can subserve speech but whether they are functionally equipotential.

Hughlings Jackson, over 100 years ago made the interesting comment that he considered both hemispheres able to represent speech but 'at very different levels in the functional hierarchy'. Involuntary speech and comprehension were regarded as low level language and possibly bilaterally organised, while propositional speech was of the highest order and unique to the dominant hemisphere. Such a position is also congruent with the views of Lenneberg (1967), who considered that at birth neither hemisphere is in a better position for language development. His evidence relies on the observation that the earlier the damage the quicker the recovery. There are however, two important points to make regarding this explanation. Firstly, Lenneberg's source of data almost solely depended on Basser's (1962) non-representative sample of children with early onset of unilateral lesion, including only severely disabled children from the National Hospital in London. Secondly, no consideration was made of evidence from other sources indicating marked individual differences in the recovery prognosis of adult aphasics, and differences in speech problems in hemiplegic children with right and left sided lesions (Dennis & Whitaker, 1977).

A more satisfactory study than the above was reported by Annett (1973) who personally assessed a complete sample of hemiplegic (impairment/loss of motor or sensory function of nerves on one side of
the body) children for hand skill on a peg moving task, verbal and nonverbal reasoning ability. Her crucial finding was that when hand skill was controlled and speech then compared, language difficulties or delays were more frequent in right than left hemiplegics. Intelligence test scores were shown not to differ, regardless of site of lesion, in those children for whom dexterity of their most skilled hand was within normal limits. How they did differ was in the greater incidence of speech disorders (stuttering etc.) in the right hemiplegic children indicating that the effect of left sided lesion was specifically to speech and not to general intelligence.

A similar conclusion to Annett's was reached by Dennis & Whitaker (1977) who after a lengthy review of both 18th and 19th century evidence, considered that: "The likelihood of language disturbances resulting from infantile damage to one cerebral hemisphere is greater with left than right lesions. In infancy, the two hemispheres are not equally at risk for disordered language" (page 95).

So, can studies of perceptual asymmetries help us to predict whether performance for verbal stimuli is different in kind between the left or the right side of the brain? What is it that the left- can bring to language processing that perhaps the right hemisphere cannot? Dennis & Whitaker report evidence that 'articulatory defects may follow early damage to either hemisphere, but that only in the left hemisphere do these articulatory problems correlate with other language disorders' (page 96).
This explanation was further advanced by Tallal & Newcombe (1978) who made the interesting suggestion that the importance of the left hemisphere's non-linguistic role in speech was its capacity to home in on rapidly changing sequential acoustic patterns in the speech code. A discriminatory device which monitors and processes the temporal order of acoustic information involved in the speech signal. While, Best, Studdert-Kennedy, Manuel & Rubin-Spitz (1989) proposed that "...listeners perceive speech patterns as coherent because they are the acoustic consequences of co-ordinated articulatory gestures in a familiar language" (page 237). They argued that as important as it is for a child to be able to discriminate between often very fine differences in the heard speech signal, they also need to be aware of such differences in articulation.

Dennis & Whitaker (1977) noted research findings which demonstrated that the right side of the brain seems to acquire specific components of auditory language less well, insofar as they affect responses to structural or syntactic aspects of spoken language.

Thus to conclude the present section, the position at this time is that while there is language capacity in both hemispheres, impairment of the left more often results in speech difficulties than when damage is to the right side of the brain. The indications are that the two hemispheres differ in their capacity for language only marginally, and that the added availability of 'fine motor co-ordination' gives the left hemisphere the edge for language development compared to the right hemisphere. This relational view of speech perception and production
in the left hemisphere may serve to provide evidence that an early
developmental influence may be sufficient to bias speech specialisation
in the left side of the brain for the majority. These findings are
more easily accounted for in terms of Annett's theory rather than by a
pathology hypothesis. Thus, because of its intrinsic importance one of
the experiments reported in Chapter 5 of this thesis was designed to
investigate associations between performance on speech perception and
production tasks and laterality.

1.3 Differences between left- and right-handers for verbal and
nonverbal ability
(a) The conflicting relationship between handedness and ability in
normal and clinical populations

Is laterality relevant to reading difficulties? Rutter, Tizard &
Whitmore (1970) recorded the results of a large survey of reading
progress and intelligence which supported the view that reading ability
was normally distributed in the population in all respects except for
an excess of poor readers over and above what would normally be
expected at the left side of the continuum. Of specific reading
retardates (poor readers in spite of adequate intelligence), 9.3% were
classed as left-handers compared with 4.8% of controls. The authors
continued to note that while all poor readers were three times more
likely than controls to have a history of generalised speech delays and
a family history of such problems, backward readers (reading below the
average for that age) were noted for their increased frequency of
clumsiness and poor constructional skills.
There is, however an important criticism of this study due to the inadequacy of the reading test used, the Neale Analysis of Reading Ability. Snowling (1987) comments that because of a ceiling effect found in the test, the best that could be expected of the bright children would never be achieved. Such an argument is ostensibly supported by the findings of Rodgers (1983), using the British Ability Scales on a sample that was normally distributed for ability, as in Snowling's study failed to replicate the Rutter et al findings of an excess of poor readers over and above that expected if ability was normally distributed. Comparable results to those of Rodgers were obtained by van der Wissel and Zegers (1985). In a computer simulation study they reported no 'hump' in the distribution of reading. Moreover, it was argued that the concept of 'specific' and 'backward' poor readers employed in certain studies of reading was obsolete as they merely specified differences of intellect. However, many studies in the reading literature recently reviewed by Snowling (1987), present evidence to show that qualitative differences do exist between children with specific reading difficulties and normal readers of the same reading age in their processing of orthographic and phonological features of written language.

Linking this finding with Annett's theory it is possible to reconstruct a theoretical picture of possible relationships between sub-types of poor readers, speech problems, intelligence, and handedness. The individual of adequate intelligence and with good manual dexterity of the left hand (right hemisphere function), but lacking the right shift factor (rs-- genotype) may respond by experiencing specific reading
disorders resulting from atypical organization of language. Equally speculative, but possible, is that poor readers who show excessive dependence on their right hand (rs++ genotype), are clumsy, have weak left hand/right hemisphere function, and below average intelligence and resemble backward readers. Rutter et al however, concluded that reading accuracy was not significantly associated with handedness. Therefore, because of its obvious importance to reading ability the second study in the present thesis was designed to investigate relationships between intelligence, reading and handedness.

A similar conclusion to that of Rutter et al was initially reached by Annett & Turner (1974), who after comparing 100 left- and 100 right-handers on a variety of ability tests found no significant between group differences. On closer investigation however, Annett & Turner noted that left-handers were over represented among poor readers of high intelligence, 15% as against 6.1% of bright right-handers (30 points above their reading quotient).

Hallgren (1950) in a study in Sweden, found 18% of dyslexics and 9% of controls to be left-handed. This pattern of results has been endorsed by several investigators over the years: Naidoo (1972) for instance, also found the same prevalence of dyslexics relative to controls among children attending a Word Blind Clinic in London and Granjon-Galifret and Ajuriaguerra (1951) reported an increased prevalence of
mixed-handers in clinic children relative to controls in young (8-10 years) but not older children (11 to 13 years).

These findings however, are rarely demonstrated in normal population samples. Belmont & Birch (1965) noted research findings which demonstrated that handedness and reading in normal Aberdeen school children was unrelated, as did Clark (1970) in a population survey of over a thousand Scottish children. Several other investigators have also failed to find significant relationships between laterality and ability when normal children have been classified for laterality and then tested for ability (Lyle & Johnson, 1976; Richardson & Firlej, 1979; Stephens, Cunningham & Stigler, 1967; Zeman, 1967).

The now familiar incompatibility in results between clinic and normal samples led Annett in 1985 to argue that "...left- or mixed-handedness is not the cause of the language difficulty but a function of the lack of shift to the right hand (left hemisphere) in the rs--. The majority of mixed-handers and some left-handers in the general population carry the rs+ gene. Hence, language skills are not expected to differ within samples (normal or mentally handicapped) as a function of handedness. But handedness is expected to differ between samples classified for language skills" (page 358).

Such an investigation of the nature of the relationship between ability and laterality was not forthcoming until 1984 when Annett & Kilshaw reported a study which compared a clinic group of dyslexics with several groups of normal controls. The distribution of hand skill differences was such that an excess of poor readers were found at both
left and right extremes of the laterality continuum and fewer at the peak of the distribution. Both male and female left-handed dyslexics were less likely than right-handed dyslexics to have a history of perinatal troubles but more chance of having speech disorders. Regardless of reading progress, excessive bias to the right hand (expected to include an increased frequency of rs++ genotypes), for both clinic and control subjects was shown to be dependent on poor left rather than good right hand skill. When samples were classified for ability and then assessed for laterality there was an effect of ability on handedness.

The suggestion that left- or mixed handers are advantaged for visuo-spatial abilities relative to right handers is inconsistent with Levy's (1969) findings of inferior visuo-spatial ability in 10 left-handed relative to 15 right-handed science students, or Annett's (1970; Annett & Turner, 1974) finding of no effect of handedness and no significant differences for ability between left-, mixed- and right-handers. Sex differences, however are consistently reported in the literature showing the relative superiority of males over females for spatial abilities right through to middle age (Harris, 1978; Wilson et al, 1975), and the increased development of language and verbal fluency of girls relative to boys (Hutt, 1972).

In Kilshaw & Annett's (1983) study of hand skill and hand preference, the effects of sex differences on the distribution of differences between the hands in peg moving time were studied. While sex differences were clear at the dextral side of the distribution of
between hand differences for actual skill with females being more biased to the right-hand than males, where the rs+ gene is assumed to be absent at the left side of the distribution, there were no differences between the sexes. Kilshaw & Annett concluded that there is no reason to expect more males than females at the sinistral end of the laterality continuum for actual skill but more females than males at the dextral extreme. However, such a proposition is at odds with a fairly general observation of more males than females in left-handers, twins and first generation relatives.

Much of the evidence cited above has been based on student samples and very little on more general populations. So, do handedness groups differ for intellectual abilities in representative samples? Wilson, De Fries, McClean, Vandenberg, Johnson & Rashad (1975) quote no effect of handedness on four cognitive factors and 15 cognitive tests between 246 left-handers and over 3000 right-handers. Likewise Newcombe, Ratcliff, Carrivick, Hiorns, Harrison, & Gibson (1975) investigated right-, left- and mixed-handers on the WAIS performance and verbal scales and again found no significant differences between handedness groups nor any indication that left-handers were better or worse than other groups.

The suggestion that the presence of some sort of left hemisphere pathology may have an effect upon left- and mixed-handers nonverbal ability gained partial support from a study by Benbow (1986). Comparing the verbal and nonverbal ability of American children pre-selected for their mathematical and verbal talents, a higher
prevalence of left- and mixed-handers were found among these intellectually precocious children than controls. This suggestion, that the presence of some sort of intellectual talent is a function of one hemisphere in isolation has not received universal approval. Annett (1985) in particular, argues that the mechanism suggested in her theory to account for left hemisphere bias is most advantageous for ability when carried in a single copy (the rs+- heterozygote), so that intellectual superiority is gained through the efficient working of both sides of the brain; more likely to be found among individuals with a mild degree of dextral bias.

Examination of Benbow’s findings indicate that she has completely failed to provide an adequate test of the hypothesis that left hemisphere pathology effects will enhance right hemisphere function or that the results have any relevance for normal population samples. Close examination of Table 1 in this report (Appendix 2) shows that not only were the intellectually talented group for mathematics over-represented by left- and mixed-handers, but also that a second sub-group of the same sample also had high verbal ability scores, which one would assume is incompatible with any left hemisphere pathology hypothesis. Secondly, the children in question were pre-selected for ability and therefore would not represent the normal, variability of hand, brain or ability, expected in representative samples.

However, Geschwind (unpublished comment, cited in the Benbow paper) made the interesting suggestion that the crucial component in verbal ability is reasoning (a right hemisphere function?) not subject
matter. Similar observations have been made by Caramazza, Gordon, Zurif & DeLuca (1976) and Eisenson (1962) who suggest a linguistic role for the right hemisphere.

The arguments relating to 'pathology determining deficit/talent' hypothesis are considered by Annett (1985) to lack parsimony, indeed she comments that: "This great weight of negative evidence should surely be sufficient to counter the left-handers' spatial disability hypothesis. However, as seen for the pathological handedness theory, slight positive trends seem to be more attention-worthy than substantial negative ones" (page 94).

To summarise the research findings to date concerning handedness and ability. In answer to the question: do left-handers differ from others for ability, there would seem some justification to assume that differences are present for some forms of language deficit. The prevalence of left-handers in clinic referrals for speech and reading problems is greater than for other handedness groups. However, the same findings fail to be observed in general, representative school samples. Annett (1985) cautions against what would be a mistaken assumption, on the basis of clinical findings, to consider disability to be causally related to handedness as prevalence of such disorders is not uncommon among dextrals.

As an explanation for the apparent discrepancy between clinic and non-clinic findings for those skills believed to be language dependent, the Annett hypothesis is an attractive one. Relevant evidence can be
explained within its concept of a gene, rs+, which when missing fails to give the extra boost to language development that is hypothesized to be gained by the majority, increasing risks of language deficits and nonright-handedness. Many of these individuals would not be included in normal sample studies but instead would feature within clinical settings. However, it does have its weaknesses - the principal one being the very real lack of a clear definition as to what the specific disadvantages for ability are for those carrying a double copy of the rs+, the rs++ genotypes.

Two points clearly arise from the foregoing; that the clinical literature generally regards the cerebral asymmetries of left- and right-handers to be causally different, and following from this, that these differences lead to, or determine differences in human abilities. These points require empirical investigation on two counts: whether such differences do exist in normal populations, and if so, the exact effects upon human performance - does it lead to an increase or decrease in talent or deficit? - and a further question, why might it have this effect?

To conclude this section, it appears that no entirely satisfactory investigation of normal population differences in relationships between verbal and nonverbal abilities and laterality have been conducted. The aim of several experiments to be reported in this thesis seeks to remedy this anomaly, and more specifically to further investigate Annett's prediction of differing patterns of ability and disability at the two extremes of the laterality continuum. The present
investigations were analysed in terms of between group performance differences.

Contemporary research in the psychology of reading has sought to discover the "cognitive architecture" of the processes involved (Ellis, 1984). One of the main goals of the present thesis was to examine the possibility that distinctions between phonological/dysphonetic and surface/dyseidetic dyslexics widely acknowledged in the developmental literature (Boder, 1973; Frith, 1979), and in adults with reading difficulties after brain injury (Patterson, Marshall & Coltheart, 1985) might be relevant to the distinction between those having too little and those having too much bias to the left hemisphere and right hand.

The empirical evidence related to reading disability will now be considered. First, a comment on the difficulties of finding a satisfactory definition will be made. This will be followed by a substantial review of studies exploring the relationships between phonological and orthographic deficits in written language. Finally, the classification systems of two contemporary investigators of childhood reading disorders will be briefly described and evaluated.

(b) Defining the problem: Reading Disability

Early theorists were not concerned with considering the distribution of reading ability in normal children. Their interests lay in explaining the symptoms of children referred to medical practitioners. As long ago as 1896, W. Pringle Morgan, a local doctor published his now famous report of a 14 year old boy with what was referred to as congenital
word blindness. The aim of this report, which can justifiably claim to be one of the first to document a developmental reading disorder, was to draw professionals' attention to what was considered a unique case:

"...in that it follows upon no injury or illness, but is evidently congenital, and due most probably to defective development of that region of the brain, disease of which in adults produces practically the same symptoms - that is, the left angular gyrus" (page 1378).

By the 1970s the World Federation of Neurology had accepted the medical model and defined dyslexia as:

[Dyslexia is] "a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin" (cited in Snowling, 1987, page 2).

It was, however, out of such medical models that the current disaffection with the term dyslexia arose. Two criticisms of this definition are: a) children from disadvantaged home backgrounds are unlikely ever to be assessed as dyslexic; b) indirect testing using neurological, psychometric and psycho-linguistic measures have shown that the deficits found in special clinic groups are also found in children who are not dyslexic (Boder, 1971; Rutter, Tizard & Whitmore (eds), 1970; Burt, 1937; Bryant & Impey, 1986).
The assumption that reading deficiency was a medical problem was rejected by many teachers and associated professionals. It was argued that the terms of referral were unclear as to whether the 'diagnosis' had been made on the basis of the neurological status of a few children and then generalized to the whole population of poor readers, or on the observed reading and spelling problem (Snowling, 1981; 1982; Snowling & Frith, 1986; Snowling & Stackhouse, 1983; Denckla & Rudel, 1976; Funnell, 1983; Patterson, Marshall & Coltheart, 1985).

In the recent literature the term 'minimal brain damage' has taken on a broad meaning, being applied not only to clinic patients but also to those children in the wider population whose suspected brain damage fails to present gross evidence of pathology. Pasamanick & Knoblock (1966) proposed a 'continuum of reproductive casualty' in that neurological effect would vary according to extent of damage incurred during pregnancy, therefore all degrees of impairment are possible. They went on to argue that minimal brain injury is similar in all respects to cerebral palsy and mental retardation, except for severity.

However, modern research has challenged the concept of minimal brain damage with Rutter (1982) arguing that "...the claims far outrun the empirical findings that could justify them" (page 21). For present purposes Rutter's comments are of special importance to the issue of how far the learning difficulties of some children are a function of variability of normal biological differences and how far they are determined by developmental pathology. More specifically when commenting on this issue Annett considers that while not denying that some cases may have pathological origins, the majority of children
with learning difficulties arise because they are extreme variants of a normal continuum of biological differences.

The first serious attempt to disentangle possible sub-types of poor readers in the general population, was that of Rutter and colleagues (1970; 1975). Multiple regression analysis showed the presence of two, overlapping sub-groups of poor reader. Two distinctions were made offering a more parsimonious definition of reading deficiency than the previously proposed medical model.

The first distinction identified 'specific reading retardates', children who were poor readers in spite of adequate intelligence. The second, was that of 'backward readers' - those children behind in their reading relative to the average child's attainment of the same age.

Identifying features were broken down even further into sex differences (3:1 males to females for 'specifics' and 1.3:1 males to females 'backwards'), neurological irregularities, clumsiness, deficiency in constructional skills (raised incidence in backward than specific reading retardates) and long term scholastic achievement levels ('specifics' 4-5 years later were making less progress in reading and spelling but more advances in mathematics).

However, a possible weakness of the distinctions were that not all children fell exclusively under each category. The nature of the child's educational and social experience, large families, fathers in low status occupations and frequency and persistence of type of error
were all found to influence reading progress. Therefore the interplay between any of these variables may differ from child to child, for some one may be of crucial importance whilst at other times they may be irrelevant. The environmental evidence amply demonstrates that not all reading problems are constitutional in origin.

One of the specific aims of the present thesis was to investigate relationships between reading ability and handedness, when intelligence was controlled for and, on reading age alone. By using a more sophisticated design it was planned to build upon the basic foundations laid by Rutter et al in investigating distinctions between specific reading retardates (those speculated by Annett to be reduced in dextral bias), and backward poor readers (those with an over dependence on the left hemisphere and right hand).

(c) The importance of phonology and orthography to reading progress
While it has always seemed highly plausible, it is nevertheless incorrect to assume that experience of speaking and listening to a language necessarily develops phonological awareness. Bishop & Robson (1988; 1989; Campbell & Wright, 1988) adopt this stance in defence of the argument that phonological awareness is available to those lacking any perceptual or articulatory experience of speech. Evidence from these authors have clearly shown that both congenitally nonspeaking and nonhearing children are able to accurately spell nonsense letter strings (nonwords) which demand an awareness of the phonological structure of a language. In numerous studies by Liberman and her colleagues (see for example 1974; 1977; 1980) speaking pre-reading
children have been shown to be unable to explicitly count, by tapping on a block of wood, the number of individual phonemes of a word, yet been able, although not with perfect accuracy, to identify the correct number of syllables. Similarly, in a study by Wagner (1988) between the development of phonological processing abilities and reading progress it was shown that the former was dependent on whether tasks involved the manipulation of single phonemes or syllables.

In a different type of study from the above Eimas (1985) provides evidence to show that learning to speak and understand language may in fact depend on perceptual categorization of acoustic information which is innate rather than learned. In keeping with the argument of Wagner (1988), that many children from normal educational settings fail to demonstrate a clear understanding and familiarity with phonology, the problematic language function of the dyslexic child is clearly stated by Frith (1985) in that "...if dyslexic children cannot cope easily with the processing demands involved in saying novel words, it is not surprising that they have difficulties in language learning" (page 465).

It is of course, eminently possible that fluent reading may be achieved by the use of different strategies. The debate is whether or not two methods, sub-lexical and lexical, are better than one when it comes to success in reading. Substantial agreement exists in current theories of reading that two main cognitive strategies exist, one based on processing the visual features of a word allowing direct access to the mental lexicon, and a second, indirect or sub-lexical route involving
acoustic-phonological processes. Bryant & Impey (1986) hold that the
special characteristics of acquired and developmental dyslexics,
reviewed by Ellis (1984), and contained in current distinctions between
phonological/dysphonetic dyslexics (who appear to have lost the phonic
building rules) and surface/dyseidetics (who make errors on words they
cannot reconstruct from sound), are also found in children from normal
schools. The important point is that these children are not considered
abnormal but part of a continuum of normal variability.

There is abundant evidence that some children when learning to read
have particular difficulty with one or other channel. It is obviously
important therefore, to study children with reading problems for
evidence of weaknesses in the two main types of strategies implicated
in the reading process (for example adequate phoneme discrimination and
visual memory for words).

One of the most frequently employed methods of experimentally
investigating differences between good and poor readers for visual and
verbal encoding, has been their ability to remember words, letters or
sentences that share common sounds compared to others that do not. An
explanation for the general finding of superior recall of items that do
not sound the same relative to those that do (the confusability effect)
in good but not poor readers draws on the distinction between the
articulatory loop and visuo-spatial sketch pad of Baddeley's (1986)
model of working memory. The inferior performance of poor readers on
nonconfusable items is considered to reflect a neglect of phonological
encoding. Verification of this finding has been made by several
investigators (Mann, Liberman, Mark, Fowler & Fischer, 1979; Snowling, 1980; Byrne & Shea, 1979; Mann, Liberman & Shankweiler, 1980; Wagner, 1988). This explanation was further advanced by studies by Bradley & Bryant (1978; 1983) who reported that some children in normal schools were unable to identify the sounds that differ between for example, HAT, MAT, FAN, CAT, and that these children were likely to be slow readers. As matched controls for reading age were used the results could not be attributed to the greater reading experience of the successful readers.

From the results of a training study, Bradley & Bryant (1983) came to the conclusion that phonological awareness was causally connected to reading progress. They employed three groups of subjects previously assessed as having phonology problems, who were subsequently trained on either phonemic awareness alone, plastic letters in combination with phonemic awareness, or semantic categorization, and a control (no training group). The group who had been trained with plastic letters in combination with phonemic awareness showed a significant improvement in reading progress 4-5 years later.

There are, however, two important criticisms of this study which casts doubt on the validity of their conclusions: 1) it is difficult to interpret the relevant phonology effects (phonemic awareness in combination with plastic letters) because they neglected to include a group trained on plastic letters alone; 2) they failed to consider the possible reciprocal nature of the relationship between reading and phonological awareness. The possibility is not eliminated that it is
skill in phonology which increases reading skills rather than the more popular notion that it is the reading which increases phonological awareness.

It would be dangerous to argue that the question has been settled over the importance of phonology to reading success. Rusted (1989) has shown that by employing the Stroop task to investigate possible relationships between phonological and orthographic priming effects, that while both visual and phonological strategies were available, younger children (eight year olds) still relied more on the sound of the stimuli while older children (twelve year olds) found both visual and verbal information intruded on the response decision. Studies by Chen & Stevenson, 1988; Rugg & Scott, 1987; Hall et al, 1987; Bradley & Bryant, 1979; Hulme, 1987; Wagner, 1988 all report findings inconsistent with the phonological encoding deficit hypothesis for poor readers.

If the hypothesis that the learning difficulties of children at the left and right extremes of the laterality continuum are causally different (having too little or too much of the rs+ gene), then the possibility arises of a dissociation between type of reading deficit in such children. Specifically, one of the experiments in the present thesis sought to test the hypothesis that children lacking the rs+ factor, the phenotypically nondextral (more likely rs− genotypes, absent of any significant left hand weakness) would suffer costs to performance on tasks which are crucially dependent on an efficient speech rehearsal mechanism.
While there is considerable evidence that phonemic awareness, syllable manipulation and rhyming skill deficits are predictive of later reading progress among some children in mainstream education (Bradley & Bryant, 1978; 1983; Snowling, 1987), it could also be argued that such effects are a function of differing teaching styles rather than because of a specific cognitive process.

A study by Lundberg, Frost & Petersen (1988) subjected pre-school children to training in so-called meta-linguistic games and exercises: listening to verbal and nonverbal sounds, rhyming games using nursery rhymes, rhyming stories and games aimed at eliciting rhyme production, segmentation of words and sentences, syllables, dancing, marching to syllabic patterns, plastic markers (non alphabetic) to encourage syllable synthesis, and finally awareness training in discrimination of phonemes and vowels. It was found that such training schedules improved later reading and spelling attainment. What seems just as possible however, is that phonological awareness could just as easily have been improved by learning to read using an alphabetic script. Although the links in the causal chain may be contentious, for instance several investigators have argued that visual and phonological processes operate in parallel rather than independently (Baron, 1973; Meyer & Ruddy, 1973), and others differ in their view of the importance of phonology (Bishop, 1989; Bishop & Robson, 1988; Campbell & Wright, 1988), there are few who would doubt the presence of either and their importance to our understanding of the writing process.
A study reported by Morais, Cary, Alegria & Bertelson (1979) of Portuguese illiterates (adults) found that one group who had received reading instruction were better at the deletion or addition of phonemes in spoken words than another untrained group. They concluded that segmental phonological awareness evolved from the training in reading. This statement echoes the sentiments of Bryant (1989) who argues the case that pre-readers' observed awareness of rhyme and non-rhyme differences indicates the importance of segmentation skills, to the beginning reader at least.

In terms of single case studies the findings of Bryant have not always readily applied. Bertelson & de Gelder (1988) found evidence that while reading skills may be dependent in some way upon segmentation skills, rhyming ability is not dependent on reading progress; their subject, an illiterate Portuguese poet, is able to rhyme on demand yet remains a non-reader.

When the present thesis was begun there was no reference in the literature to studies which addressed the specific question of whether there was an association between phonemic confusability effects and laterality. Therefore, a primary aim of one of the experiments reported in Chapter Five of the present thesis was to ask this question.

While there is generally less empirical evidence that a word can be actively maintained in its visual form in memory, the very nature of the English language is ample argument against phonic mediation as the
sole explanation for all reading problems. Evidence that some level of fluency in reading can be achieved without an ability to decode by sound is well documented in the literature. Frith (1979) for instance, found that by manipulating the task, subjects could be shown to be reading via a visual, orthographic strategy. Skilled readers, on a letter cancellation task were asked to strike out any e's that they found, as quickly as possible on a series of single printed words. The list of words included instances where the target letter was stressed or unstressed, and placed equally as often at the beginning, middle or end of the word. Examples of stressed e's were in words such as 'CENTURY' 'PROFESSOR' or 'SUCCESS', and unstressed e's in words such as 'DELIGHT' 'LIBERTY' and 'INNOCENT'.

No difference was found between the cancellation accuracy in stressed or unstressed conditions, or when the target was at the beginning or middle of the word, but all subjects were poorer at detecting targets at the ends of words. This lack of a phonology effect (difference between stressed and unstressed cancellations) suggests that phonological encoding is not mandatory, for skilled readers at least, unless we consider that phonological processing only applies to the ends of words.

Frith suggested that automatic processing may only demand partial visual scanning in order to get to meaning, therefore skilled readers may be more likely to miss the tail end of words if they have enough information from the first part. Among other findings, results from the Stroop task have also indicated that reading can proceed 'by eye'
as well as 'by ear' in that subjects' accuracy of pronunciation is interfered with when colour and name are incongruous.

A second question relevant to Chapter Five of this thesis is how homophone (words that sound the same but are spelt differently) discrimination proceeds. This task cannot be successfully completed by a phonological strategy, but must rely on memory for spelling, which is likely to be a visual, orthographic representation. In terms of the RS Theory Annett argues for a dissociation between visual and verbal processing accuracy in those individuals at each extreme of the hand skill distribution. The deficit assumed to be associated with those at the dextral extreme (including more rs++ genotypes) is the inaccurate matching between phonological and visual features of language; those at the sinistral extreme are more at risk to generalised problems of phonological encoding.

Now, while the questions in all the above studies were specific to processing strategies hypothesized to underlie reading, consideration must also be given to the possible effects of memory and its involvement in word recognition. One hypothesis to come from the literature to explain how problems in working memory might be implicated in learning to read was advanced by Baddeley (1986). The importance of this model to the RS Theory can be seen once it is realised that the concept of an input and output system that underlies the temporary storage of information, believed necessary for information processing tasks such as reading, is implicit in Annett's speculation that "the advantages of the rs+ gene depend on its
pronotion of the more efficient arrangement of having both ends of the loop in the same hemisphere rather than in different hemispheres" (Annett, 1985, page 402). The experimental predictions of the model do therefore, in some measure, provide a way of empirically evaluating the RS Theory.

Recent work on the role of the input and output processes of the model has suggested that deficits at the stage of input might be characterized by phonemic confusability effects, poor rhyme judgements and auditory matching skills. While output problems might be demonstrated by deficits in fluent speech, repetition and nonword reading performance. Two studies are of particular interest: Baddeley, Eldridge & Lewis (1981) and Baddeley (1975).

Baddeley, Eldridge & Lewis (1981) presented strong evidence that the nature of the articulatory loop is speech-based. Any material presented in a visual form has to be registered first and then translated into a phonological form. For example, when subjects were asked to read text and at the same time make non-associated sub-vocalizations (articulatory suppression), there was a failure to detect meaningless embedded text.

In an experiment of somewhat complex design Daneman & Carpenter (1980) presented subjects with a series of unrelated sentences and asked for the final word to be remembered while processing the next sentence in the sequence. The results indicated a significant correlation between reading span and working memory capacity. A subsequent study by
Daneman & Tardif (1987) supported Baddeley & Hitch's (1974) contention that the articulatory loop and visuo-spatial sketch pad were separate processing systems. Presenting subjects with verbal, mathematical and spatial memory tasks, the authors reported that while verbal and mathematical span correlated with reading, spatial span did not. In the field of experimentation into short term storage and processing of verbal material Baddeley's model has been successful in advancing current knowledge. However, the visuo-spatial sketch pad is less well understood possibly because it has proved more difficult to find an experimental technique analogous to articulatory suppression in the verbal area of investigation which allows disruption of visuo-spatial cognitive processing.

Baddeley (1975) found that when restricting the time available for recall, subjects typically only remembered that which they could say in about two seconds. Baddeley suggests that rehearsal acts as "a checking mechanism that is particularly good at preserving the order of information (page 177 Baddeley, 1986). Obviously, any processing task that demands order, as in the case of a listener who is subsequently asked to recall a telephone number or sequence of instructions, demands some form of rehearsal mechanism.

In terms of the RS Theory the findings of Baddeley are most readily applicable to the suggestion that some form of speech output-input structure is included in Broca and Wernicke's areas to encourage co-ordination between what is heard and what is said. The suggestion that the absence of some factor may adversely effect the organization
of input-output in the left hemisphere has been made by Annett (1985). She suggests that, with respect to rs-- genotypes, the speech input-output loop organization could be in both or either hemispheres, simply because of random development in the two sides of the body. As noted previously (page 13) those believed to be at greatest risk to poor language skills, those poor readers at the left tail of the laterality continuum (more likely rs-- genotypes) would be most at risk for poor phonology skills. Translated into a working memory hypothesis those least advantaged in articulatory loop efficiency (i.e. sinistrals and strong dextrals) would be at opposite tails of the inverted U function, while those most advantaged (mild and moderate dextrals, with a heightened frequency of rs+- genotypes) with good verbal and visual encoding skills, would be in the main body of the distribution.

However, one of the major criticisms of several recent studies concerns phonology as a measure of reading deficit. Typically, segmentation tasks are used to distinguish gross differences between good and poor readers when, what they fail to do is to separate what may be quite subtle deficit differences within groups of unsuccessful readers. Bishop (1989) goes on to comment that the main drawback to much of the current work in this area is its vagueness as to which specific aspect of phonology is being described. This is consistent with the suggestion of Patterson (1989) that the term phonological awareness in relation to reading skill carries a somewhat narrow interpretation for what in reality may be a 'complex collection of skills' which interact rather than cause literacy.
It is clear from the above section that opinion differs widely amongst theorists as to the importance of phonology, in isolation, to the reading process. While psychologists working on applied and theoretical problems related to the distinction between visual and phonic methods of reading have clearly identified poor readers who present deficits in speech sound recognition (Bradley & Bryant, 1985), there is also evidence that other poor readers have weaknesses in visual word recognition (Seymour & Elder, 1986). It is, however, extremely difficult to devise a definitive experimental design which can dissociate visual and verbal processes believed to underlie reading proficiency. However, as all laterality theories, including Annett's, are expected to make statements about the language and nonlanguage relationships between the two cerebral hemispheres, it is important to ask whether the phonological and visual routes to word recognition distinguished in recent models of the reading process contribute to our understanding of developmental dyslexia and its association with handedness. The method of investigation in the final two chapters of this thesis was to look for experimental evidence of deficits in the two main types of processing requirements for reading, efficient phoneme discrimination and visual memory for words.

The specific learning difficulty of dyslexia is considered a complex syndrome which causes difficulty in learning to read, problematic spelling, and a general difficulty in manipulating written as opposed to spoken language. Issues have revolved around whether the primary handicap involved is perceptual, linguistic or both. Research into its aetiology has been similarly diverse. Heredity factors have been
investigated largely because dyslexia is reported more frequently in boys than girls, and may therefore indicate a sex linked genetic disorder. However, it is not a unitary disorder and different types of dyslexics present different combinations of difficulties. The next section briefly reviews and evaluates one recent theory of reading, that of Frith (1985), and one diagnostic screening model, that of Boder (1973) which directly investigates different patterns of reading style.

1.4 Classification systems of developmental dyslexia

A definitive classification and exact understanding of the nature and mechanisms underlying childhood and adult reading disorders, is at the time of this research, lacking. Nevertheless, Boder (1971; 1973) and Frith (1985) have each proposed sub-types of developmental dyslexia to account for the variety of developmental reading difficulties reported in the literature.

(a) Boder (1971; 1973): A Diagnostic Screening Model

Boder employed a diagnostic approach in the investigation of relationships between visual and verbal deficits and reading. The results of a study of 100 dyslexics (using the World Federation of Neurology definition, see page 38) produced evidence on the basis of error type, of two discrete groups plus a third sharing the features of the first two. The broad findings of this study were that: a) 67% of the sample were dysphonetic, presenting a weakness in phonology and an over-reliance on sight vocabulary; b) 9% were dyseidetic in that they demonstrated good phonetic skills but poor orthographic awareness; c) 24% showed primary deficits in both phonetic word analysis-synthesis skills
and in the perception of letters and words as visual wholes.

These distinctions have important implications for the RS Theory: If the positive nature of the rs+ gene is to advantage language growth, then it must be expected that strong right handers (including more rs++ genotypes) would be especially advantaged for language skills; however, if such gains are only met at a cost to right hemisphere visuo-spatial impairment, then verbal encoding is likely to be a generalized strategy employed to process all incoming information in the same way as Boder's dyseidetic group. Similarly, if the rs-- fail to gain the extra boost to language assumed to be carried by the rs+ gene, then encoding the visual features of incoming stimuli is assumed to be the preferred means of processing at a neglect of verbal encoding, as is the case with dysphonetic poor readers. Thus, the hypothesis that both rs-- and rs++ genotypes would be more at risk to reading difficulties can be directly tested within the Boder diagnostic screening model. A full description and the rationale underlying the Boder screening procedure is available (Boder, 1971; 1973) and therefore will not be repeated here.

Boder (1971; 1973) used both the 'look and say' technique (the child is presented with a word printed on a card and has to make an immediate response), and a condition which allowed the child as much time as was necessary to make a response, (an untimed condition to allow the use of 'phonics') in her investigation of possible relationships between sight vocabulary and reading deficit. The findings are therefore not restricted to reading performance but also allow a measure of spelling
ability. Boder found that with regard to between-group performances dysphonetics made fewer spelling errors on known than unknown words, their mistakes were unlikely to be phonetically plausible, but they had a good sight vocabulary relative to dyseidetics, who had good phonic skills but were poor at processing the visual features of words. The combination group, dysphonetic/dyseidetic reflected primary deficits in both verbal and nonverbal processing of written language. Indeed Boder found that a single predictor of dysphonetics was poor nonword reading while for dyseidetics it was regularity effects (better at reading regular words relative to irregular words).

However, as Snowling (1987) notes there is no clear evidence that the processing deficits described actually cause any difference in reading progress between the groups. Snowling goes on to comment that the word lists used by Boder included visually distinctive words such as 'YACHT' or 'BUREAU' discouraging even those children with good phonic skills from attempting a response. If, as Snowling suggests, non response was taken as an indication of absent phonology then the classification and subsequent remediation may be erroneous.

The deficits outlined above relating to a possible dissociation between visual/orthographic and verbal/phonological encoding in patterns of deficit between sub-types of poor reader can be seen to be analogous to Annett's hypothesised excess of poor readers expected at left and right extremes of the laterality continuum. The present work sought to add to this growing body of research by providing fresh experimental evidence on a dissociation between sub-types of poor spellers at each
end of the laterality continuum.

With regard to control and experimental groups Rack & Snowling (1985) compared dyslexics with reading age matched controls and found the former gave a poorer auditory processing performance. There is however, an important point to make regarding reading age matched designs: while controls and experimental groups do not differ in their reading ages the cognitive strategies available may not be the same for both. As Thomson (1984) has argued, the exact relationship between 'delay' or 'deviance', a pattern of performance which is normal but indicative of an earlier developmental period or failure to follow a normal sequence at all, remains unclear.

(b) Frith (1985): A Three Stage Theory of Reading

One recent theory of developmental reading acquisition is that of Frith (1985). Frith suggested that deficits of reading and spelling are linked to a sequence of developmentally evolving stages, which she referred to as: logographic, alphabetic and orthographic. Included within each stage is the acquisition of different visual and verbal strategies believed to be available and transferable to the next phase of development. Table 1.1 presents the processing skills included within each phase.

It can be clearly seen from Table 1.1 that none of the skills are exclusive to any one stage; novice readers are not prevented from accessing information typical of a more advanced stage, and the skill characteristics of early stages do not become unavailable to the
TABLE 1.1 FRITH'S MODEL OF READING (CITED IN SNOWLING, 1987)

![Diagram of Frith's model of reading]

Figure 4.2. Model of the interface between spoken and written language processing systems
A point of interest lies in the finding that reading and spelling problems do not necessarily go together (Bradley & Bryant, 1979; Frith, 1979; 1980; 1983; Marcel, 1980; Perin, 1983). Frith (1979) comparing good readers and good spellers, good readers and poor spellers and a third group who were poor on both, found that while good readers made mainly phonetic errors (those attempts which on reconstruction through "sounding out" individual letters would result in a plausible pronunciation), poor readers made a mixture of phonetic and nonphonetic spelling mistakes. Likewise, Bradley (1988) found that it was not unusual for six year olds to read correctly the word 'SEE' yet spell it as 'STL' or write 'MAT' correctly yet read it as 'MAKE'. These findings might imply that a single processing mechanism underlies both reading and spelling, in that 'making the connection between letters and sounds' is the determinant of success in both. However, Frith considers that what evidence is available on relationships between reading and spelling does not support such a contention. More specifically, Frith argues that writing (spelling) proceeds as it is heard (by ear) rather than how it looks, and reading 'by eye' (how it looks) rather than how it sounds.
The nature of the logographic stage, is essentially one of pairing the visual shapes of words with how they are spoken, not unlike attaching labels to pictures, even though little awareness of how individual letters are represented phonemically is expected. Any ability to read continuous text is assumed to be narrative in kind and derived piecemeal from the meaning of isolated words.

Support for the paired associate learning at this initial stage, came from studies by, for example, Seymour & Elder (1986) and Gough & Hillinger (1980). This explanation was further advanced by Marsh et al (1980) who proposed that whole word reading, or visual encoding, was not helpful to spelling and this was why so few spelling attempts are generated at this stage. In a similar vein, Snowling (1987) came to the conclusion that in order for children to 'abstract and use letter-sound relationships, capitalizing upon the alphabetic relationship which is embodied in printed words' they need to move forward to the next phase of development, the alphabetic. She comments that, with respect to unfamiliar words or spelling, the child remaining at the logographic stage would lack the necessary skills to attempt recognition of, or write unfamiliar words. It is the failure to move beyond the logographic stage, building on the skills already gained, that Frith argues is typical of the developmental dyslexic.

Thus the model combines the factors assumed to be important to reading and spelling progress - cognitive and experiential. The experimental predictions of the theory are that problems in reading and spelling are due to deviant developmental progress. However, Campbell & Butterworth
(1985) provided evidence that fundamentally questions the Frith rationale. They demonstrated that their subject R.E. who was a fluent reader, nevertheless failed to indicate a progression beyond the logographic stage.

The second stage of development, the alphabetic, opens the way for both reading and spelling of novel words through awareness of the correspondence between letters and sounds and by making more explicit the principles previously learnt of alphabetic correspondence expressed in written words. Perfetti & Hogaboam (1975) make the point that the Frith hypothesis of a stage-like progression with increased performance at each stage might imply that there is an immediate acquisition of knowledge at some predetermined threshold, however it is considered by Frith that the improvement in skill is a continuously evolving process.

It should be noted however, that there is uncertainty surrounding what Frith means by letter-to-sound processing acquired in this second stage; if what is actually being referred to is grapheme-to-phoneme correspondence then there is clearly no equivalence between this and individual letter-to-sound connections. More specifically, if a child is presented with the word 'FRESH' making connections between the individual letters and their respective sounds could result in five 'bits' of information, i.e. f, r, e, s, and h - for most beginning readers this would not correctly identify the target word. However, if units of sound, in the form of grapheme-to-phoneme correspondence were used, i.e. fr, e, sh, then there is an increased probability of successful word recognition. If the generally accepted definition of a
grapheme, 'a group of letters representing a single phonemic unit' is what is really being described, then the alphabetic stage does not adequately account for how such a skill is facilitated. The final stage, the orthographic, is regarded as one of automated processing characteristic of adult skilled reading. A time of blending together the knowledge gained in the previous two stages, when the child's familiarity with clusters or units of graphemes does not demand explicit phonological transposition.

In terms of individual differences in spelling, Annett's theory is an accommodating one: relevant evidence can be accounted for within its boundaries. Translated into a 'Right Shift' hypothesis good and poor spellers would mostly be found in different parts of the inverted U function of the suggested relationship between reading/spelling ability and the laterality distribution; those least able being at opposite ends of the distribution (i.e. rs-- and rs++ genotypes), whilst good readers/spellers (i.e. heterozygotes rs+- genotypes) being at or near the peak of the distribution.

The laterality literature provides little in the way of explanation for individual differences in spelling performance. However, clinical work has provided evidence that insult to specific cerebral areas (the left angular gyrus) can result in differences in spelling performance (Sasanuma, 1975; Pizzamiglio & Black, 1968), a specific deficit in spelling nonsense strings (Langmore, 1979), while Gazzaniga & Sperry, (1967) and Zaidel (1978) consider the right cerebral cortex unable to process phonemically based information, limiting its role in spelling
to one of orthography.

As the effect of visual and verbal encoding is such a basic issue for this thesis, the final study was designed to investigate the hypothesis that nonword spelling is likely to be more difficult for those with poor phonological processing (rs— genotypes) and irregular word spelling more likely a problem in those with poor visual memory for words (rs++ genotypes), at left and right extremes of the laterality distribution respectively. By using a more sophisticated design it was planned to identify dysphonetic/phonological and dyseidetic/surface sub-types of poor spellers in order to build upon the basic foundations laid by Boder and Frith in this area of research.

The present investigations sought to provide more information on the question of relationships between ability and lateral asymmetries; specifically looking at the problem within the context of Annett's (1972; 1985) RS Theory and its suggestion of a human balanced polymorphism with heterozygote advantage for ability.

1.5 Aims of the thesis

The present research strategy sought to replicate the findings on reading and laterality reported in Annett & Kilshaw (1984) in a normal population, and to expand them further by asking firstly, whether the terms dysphonetic and dyseidetic dyslexia tell us anything about types of reading problem in a normal population of school children, and secondly, what links there may be between these types and lateral asymmetry. A number of specific empirical hypotheses have been derived
from Annett's suggestion of a human balanced polymorphism with heterozygote advantage for ability. These hypotheses will be clearly stated in each of the studies to be reported upon in the following pages.
2.1 Introduction

Collection of data for the present thesis involved assessing children on an individual basis using a common core of tasks which were administered in a fixed order to all, plus various other tasks the combination of which differed according to the specific hypothesis under test at that stage of the investigation. In addition, group data were collected when children were assessed in complete class groups. Their tasks included paper and pencil analogues of some of the tasks given to the children who were seen individually.

The primary aim of the present investigation was to study a general, unselected, and representative population of school children. In order to assess developmental changes in certain tasks the participation criteria involved seeing all children in whole classes, selection being on the basis of age. Therefore, for some purposes children aged 7, 9 and 11 years of age will be reported upon whereas in other parts of the thesis only the very young children, 5 and 7 year olds, will be described on tasks that were both common to them and the whole sample but also on tasks that were unique to their age group alone. Bearing this in mind the ages in any one class range over the whole 12 months defining that class.
This chapter will be in three parts. The first will be a general outline of subjects and procedures while the second will be specific for particular data. The final section reports on supplementary information, (given in confidence) which was made available by schools regarding individual children, followed by a brief statistical note.

2.2 General outline of subjects and procedures

(a) Subjects

Subjects were 353 state school children from six schools in the West Midlands and Warwickshire (1=inner city, 1=rural, 2=surburban, 2= mixed rural and council estate). Ages ranged from 5 to 11 years, (175 males and 178 females) - all children were assessed individually by one of two examiners. In addition group data was collected from whole classes of children, many of whom had been seen previously for individual testing, N=440 (223 males and 217 females).

(b) Schools

Children individually tested were from all six schools while children tested in whole classes for group data were from schools 4 and 6 only.

School 1 - this school took the entire age range from 5 through to 11 years of age (here we asked for 7, 9 and 11 year olds). Schools 2, 3 and 6 were all Middle Schools with children aged between 8 and 11 years of age so here we asked for 9 and 11 year olds. Schools 4 and 5 were First Schools with children aged between 5 and 7 years of age, here we asked mainly for 7 year olds but saw some younger children for particular sub-experiments.
A sub-sample of the children (n=16) were identified as not having English as their first language at home. A t test comparison between these children and the remainder of the sample across all variables to be discussed in this thesis found several significant between group differences (Table 2.2.1 presents these comparisons). The two groups of children shown in Table 2.2.1 can be seen to differ significantly for left hand and between hand skill, reading quotient and teachers' maths ratings. The possibility that the differences noted above could be due to socio-environmental factors such as parental level of education, unfamiliarity with the written and spoken structure of the English language and the active discouragement in some cultures of questioning adults, especially teachers as to whether what is required has been understood correctly could not be ignored. Accordingly, these children are sometimes excluded from the analysis when this seems appropriate and this is noted within the text and tables.

2.3 Assessment Procedures

(a) Physical features of the test situation

Children were brought in pairs from their classrooms and tested in the same room by two examiners. Children were seen in the order of their classroom register. Working in pairs gave confidence to the children and increased speed of data collection. The presentation of the tasks was scheduled so that while one child was being tested for reading the other was wearing headphones for a listening task. Organization of the room was such that children were tested 'back to back' and at opposite
TABLE 2.2.1
T-TEST COMPARISON BETWEEN CHILDREN WHOSE PRIMARY LANGUAGE AT HOME IS NOT ENGLISH (N=16) AND THE REMAINDER OF THE SAMPLE

KEY:
GROUP 1 - MAIN SAMPLE
GROUP 2 - HOME LANGUAGE NOT ENGLISH

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<td>2.03</td>
<td>259</td>
<td>.044</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>3.2</td>
<td>1.0</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
sides of the room, making it difficult to either hear or observe the other child's participation on tasks.

(b) **Laterality Assessments**

(i) **Peg Moving** - This task shown in Appendix 3 involves the child moving a row of 10 wooden dowelling pegs, 5.08 cm (2") long, one at a time from one row of holes (1/2" diameter, 7/8" deep and 1" apart) to another parallel one 8" away and towards the body (children were not allowed to grasp two at once). The peg board was placed on a table of convenient height for each child when standing. A single trial involved moving all ten dowelling pegs from the furthest row of holes to the nearest row as quickly as possible.

Alternating hands, each child completed between 3 and 5 trials. The variation in number of trials was to prevent the younger children from getting overtired due to the number of tasks being included in the assessment and in some instances due to time constraints in older children. Choice of 'start' hand was given to the child with each trial being initiated by the examiner's instruction of "ready, steady, go". Duration of each trial was timed from when the first peg was touched to release of the last, and recorded in 1/10 seconds using a standard hand held stopwatch. Children were told of the time taken on each trial and encouraged to go faster next time.

**Scoring** - Mean raw times for each hand were calculated and then transformed into standardized scores using right hand norms for both hands (Annett, 1970), Mean 100, SD 15, see Appendix 4. Standardization
of hand speeds are necessary because, although as people get older the
difference between their hands seldom varies, the actual skill of each
hand can; for instance a child of 5 is more likely to be slower with
both hands than a child of 11 and while the child of 5 will probably
get faster with both hands as he/she gets older the difference between
the hands remains relatively constant. Therefore, including children
of different ages needs some common measure to control for possible age
effects.

(ii) Hand Preference - Each child was observed either performing or
miming 7 acts. The actions were: writing, throwing, using a bat,
striking a match, hammering a nail, cleaning their teeth and dealing
playing cards.

Instructions for each individual action
"Show me how you write your name, throw a ball, bat a ball with the
bat, pretend to strike a match, pretend to gently hammer a nail,
pretend to clean your teeth and, deal the cards as if we were going to
have a game" (using a real match box, toy hammer, child's toothbrush
and playing cards).

Materials - wooden hammer, ball, table tennis bat, pencil, box of
matches, toothbrush and standard pack of playing cards. The materials
were always displayed on a table top and the child invited to pick them
up and perform the actions, this allowed freedom of choice of preferred
hand.
Scoring - children were classified on the basis of their observed performance on the above, using Annett's (1970) criteria - detailed below. Preferences were classified as follows:

CLASS 1 - Right, pure (using the right or either hand for every action)
CLASS 3 - Right, moderate left
CLASS 4 - Right, strong left
CLASS 6 - Left, strong right
CLASS 7 - Left, weak right
CLASS 8 - Left, pure (using the left or either hand for every action).

The classifications match those described by Annett (1970), with re-definitions of classes 3 and 4 (omitting class 5). Closer examination of previous data examining the association between hand preference and hand skill had indicated to Annett (1985, pages 219-223) that individuals in class 5 included some who carried out only one primary action with their left hand (which was not dealing playing cards), had a mean difference between their hands in skill (L-R) more like those in hand preference class 3, and others who performed two primary actions with their left hand (including dealing playing cards), resembled more closely the mean L-R skill of hand preference class 4. On this rationale Annett re-defined the hand preference classification into 7 groups, excluding the previously mentioned class 5. Appendix 5 gives hand preference classifications in more detail. Class 2 was not used in the present thesis as the actions defining that class.
(sweeping, digging and needle threading) were not assessed in this sample.

2.4 Measures of intellectual ability

(a) Non-Verbal Reasoning (Ravens Matrices, 1963, Bookform) - All children aged 5 to 9 years of age were administered sets A and Ab of the Coloured progressive Matrices (Raven, 1963). Appendix 12 gives one example from the test. This test involves showing the child sequences of incomplete abstract shapes and asking them to point from a choice of several, the one they think will correctly complete the pattern. Children 10 years and over were examined on sets A, Ab and B. Order of presentation was A, Ab and B, with instructions as laid down in the Test Manual (page 16). Percentile scores were calculated using the 1982 norms for Scottish children (Raven, Court & Raven, 1984).

Scoring

Percentile scores for the older children were looked up directly from the 1982 norms (Raven, Court & Raven, 1984). A total score pro rated from the sum of sets A and Ab was used for the younger children, (using the Tables VIII and IX, page 38 in the Test Manual), due to time constraints in testing so many children individually, and because younger children are not expected to get many of set B correct.

(b) Reading (Schonell & Schonell, 1952 short form) - Figure 2.4.2 presents the Schonell Reading test.
FIGURE 2.4.2 SCHONELL READING TEST (SHORT FORM), SCHONELL & SCHONELL (1952)

| tree        | little | milk      | egg       | book       |
| school      | sit    | frog      | playing   | bun        |
| flower      | road   | clock     | train     | light      |
| picture     | think  | summer    | people    | something  |
| dream       | downstairs | biscuit | shepherd  | thirsty    |
| crowd       | sandwich | beginning | postage   | island     |
| saucer      | angel  | ceiling   | appeared  | gnome      |
| canary      | attractive | imagine | nephew    | gradually  |
| smoulder    | applaud | disposal  | nourished | diseased   |
| university  | orchestra | knowledge | audience  | situated   |
| physics     | campaign | choir    | intercede | fascinate  |
| forfeit     | siege   | recent    | plausible | prophecy   |
| colonel     | soloist | systematic | slovenly  | classification |
| genuine     | institution | pivot | conscience | heroic     |
| pneumonia   | preliminary | antique | susceptible | enigma    |
| oblivion    | scintillate | satirical | sabre     | beguile    |
| terrestrial | belligerent | adamant   | sepulchre | statistics |
| miscellaneous | procrastinate | tyrannical | evangelical | grotesque |
| ineradicable | judicature | preferential | homonym | fictitious |
| rescind     | metamorphosis | somnambulist | bibliography | idiosyncrasy |
Instructions
"I have some words here which I would like you to read out aloud. They start off very easy but soon get hard. Shall we see how many you can read". The examiner stopped testing when (a) the complete test was finished or (b) when a complete reading year (10 words) was incorrectly identified or not attempted.

Scoring
Reading quotient (RQ) and reading age (RA) in months, were calculated using the accepted form of RA/CA (Chronological age) x 100. One year being classed as ten consecutive words correct. All incorrect attempts were noted verbatim. In addition to the reading measure of RQ referred to in Chapter 4 of this thesis, regression scores were also used in order to identify children whose reading was poor in relation to their intellect but not their chronological age. In order to investigate possible associations between this group of 'poor readers' and laterality the statistical technique of multiple regression was employed which allowed a regression score to be computed. The statistic calculates a child's expected reading ability when both intelligence and age have been accounted for. In the present thesis the Ravens Matrices raw score served as the measure of intelligence.

The equation comprised number of words read (RA), age in months (CA) and raw score for the Ravens Matrices (IQ) for the whole sample. The computer print out gives observed RA, predicted RA, the residual and standardized residual value for each child when CA, and raw IQ score is controlled for. These standardized residual scores were then added to each child's record in the data file and referred to within the text (Chapter 4) as 'stresid' scores (the dependent variable).

2.5 Procedures specific to particular sub-experiments

(a) Handwritten spelling to dictation - In brief, children were
required to listen through headphones to a series of words and nonwords and requested to write what they heard on paper provided. Appendix 6 provides a complete list of stimuli presented. Full procedural details are given in Chapter 6.

(b) Rhyming (Bradley & Bryant, 1983) - Bradley & Bryant's 'odd one out' task requires that the child listens to several words, all of which rhyme except one which does not. The child is then asked to tell the examiner which was the non-rhyming word (see Appendix 7). Full procedural details are given in Chapter 5.

(c) Homophone discrimination - Complete classes of children were asked to listen as one examiner read aloud a list of sentences. The sentences included a target word which could be spelt in more than one way (see Appendix 8 for homophone pairs). Each child was provided with a prepared printed answer sheet of pairs of words (Appendix 9), both sounding the same but only one which had the correct spelling for the 'target' in the originally presented sentence. The children were asked to listen to each sentence and then circle the word which was the correct spelling and the right meaning for the target word. Full procedural details are given in Chapter 5.

(d) Word order test - Children were asked to listen to an auditory presentation of a series of words (recorded by a male in a neutral prosody) and played through a loudspeaker. Some of the trials included words which had some aspect of sound in common, for example the first, medial or final phoneme, and other trials included words where no
similarities for sound were apparent. The task involved the children listening to each trial, and then making a handwritten note on a pre-printed list, of the order in which the words had been heard - the printed order being different to the heard presentation. Appendix 10 gives the series of words in full. Full procedural details are given in Chapter 5.

(e) Peg Moving analogue - 'Lines' - This task is an exploratory experimental attempt at providing a group test of actual hand skill that could be used as an alternative to the individual assessment demanded of the peg moving board. Each child was provided with a pencil and pre-printed booklet (Appendix 11).

Instructions
Demonstrating at the blackboard, the following instructions were given: "Watch what I do on the board, but do not pick up your pencils yet. I shall ask you to start with the pencil in the RIGHT HAND START BOX. This is like getting on your mark for a race. When I say 'ready, steady, go', draw through the middle of the squares as fast as you can, keeping your pencil on the paper and following the order shown by the lines, like this (experimenter then demonstrates at the board).

The score will be the number of boxes your pencil marks, without over-shooting. It does not matter about drawing neat lines, any lines will do provided you keep the pencil on the paper. I hit these squares correctly but here I went too far and overshot. If you make a mistake do not stop, just carry on as fast as you can, but try not to make too
many mistakes".

"Does everybody understand what they have to do?" Any questions were answered by repeating the blackboard demonstration.

There were two practice trials, followed by three test trials. Alternative trials for right and left hands were used throughout. Each trial lasted for 11 seconds and was timed using a standard, hand held stopwatch.

**Scoring**

Trials were scored for number of 'hits' for each hand, i.e. how many times for each hand the child managed to hit the target. These were then summed and averaged for each hand, the difference between the hands (right minus left) then being calculated.

(f) Points that were noted during the testing session

1. Any child whose performance deviated significantly from the instructions, such as continuing to draw after the end of each trial. Written notes of such occurrences were made.

2. Any comments or suggestions on the intelligibility of the instructions or test administration were encouraged and noted.

2.6 **Confidential information from teachers**

Each school made available information regarding the following:

1. Parental country of origin if not British.
2. Language spoken at home if not English.
3. Notification of any hearing, eyesight deficiencies, mental or physical handicap.
4. Any known emotional or social problems.
5. Standardized test scores for both English and Mathematics.

Schools 2 and 6 provided scores from the Richmond Tests of Basic Skills (Hieronymous, Lindquist & Fraser, 1975). School 3 provided scores from NFER (1975) tests for English Progress and Mathematics Attainment Tests. Scores for the first year children were from tests B1 and B2, and for the third year children from tests D2 and DE. Standardized test scores were not available from schools 1, 4 or 5. These schools however, provided teachers ratings for both mathematics and English. The rating scale was as follows:

(1) GOOD  (2) ABOVE AVERAGE  (3) AVERAGE  (4) BELOW AVERAGE  (5) POOR

2.7 Statistical analysis - all analyses were carried out using the SPSSX (SPSSX Inc, 1986) statistical package on the University of Leicester's mainframe VAX computer. Pooled variances were always used on t test comparisons and weighted terms used for tests for trend.
3.1 Introduction
This first experiment aimed to investigate three factors thought to be relevant to the study of lateral asymmetries. These three factors are hand preference, hand skill and nonverbal reasoning ability and their distribution in a normal population, unselected for either handedness or intellect. An additional factor, sex differences, was also included in the experiment. Variations in the skill of each hand, between hand differences, and intellectual ability, between mild and strongly right-handed children were also explored. Thus the experiment had several objectives, the first being to build on the findings of Kilshaw & Annett (1983) which indicated that bias to the right hand in the strongly dextral was due to left hand weakness rather than right hand strength. An expansion of the Kilshaw & Annett finding was also looked for in terms of possible disadvantages for nonverbal ability associated with excessive dependence on right-handedness.

From the many possible questions relating to asymmetries of function the present experiment sought to look at one aspect in particular: The distribution of handedness and nonverbal ability. Specifically the experiment aimed to determine whether intellectual ability would differ between handedness groups, or between the sexes.
The possibility of individual differences in hand preference and ability resulting from variation in brain organisation was noted over sixty years ago by Orton (1925): "Mirror writing with the left hand is an expression of the symmetry of build of the body. This is obvious when we consider that, so far as the motor mechanisms are concerned, any innervation of the muscles of the left hand will give a motion exactly opposite to that resulting from the comparable innervation applied on the right" (page 599).

More recently, Geschwind & Behan, 1982; 1984 (Galaburda & Kemper, 1979; Galaburda, 1983; Gordon, 1980; Peterson & Lansky, 1974; Annett & Kilshaw, 1982) have also commented on associations between higher rates of left-handedness and impairment or superiority of intellect. Modern evidence also generally supports the view of male-female differences in ability patterns (Maccoby & Jacklin, 1984; Benbow & Stanley, 1980; Rutter & Yule, 1975). Whether these findings apply to normal, unselected population samples will be determined by the present experiment. The present study aimed to investigate further these general findings from clinic and school samples, by examining degrees of right-hand bias in relation to sex differences and nonverbal intelligence.

A further point concerns the possibility of a separation of right-handedness into a number of sub-divisions: It is suggested that these sub-divisions be called 'mild' 'moderate' and 'strong' dextrality, the obvious distinction between the three being in terms of
their differing degrees of bias favouring the right hand and, as such, the possible variability of nonverbal reasoning which is of crucial theoretical and practical importance to, for example, scholastic progress. A further aim of the present experiment therefore, was to examine expected differences in both handedness and ability between mild and strongly dextral children.

This first experiment includes a large, unselected population of schoolchildren assessed for measures not previously included in a study of laterality and ability, and seeks to both present confirmation of previous findings together with new findings and conclusions. The general hypothesis of this first experiment is that strong dextral/left hemisphere bias (including an increased proportion of rs++ genotypes) will carry costs for ability while mild/moderate dextrals will be most advantaged (including more rs+- genotypes).

Secondly, it is predicted that the risks for ability are associated with a functional weakness of the right hemisphere, therefore strong dextrality is expected to be associated with poor left hand skill rather than right-hand strength.

3.2 Summary of Method and Procedures (Full details in Method Chapter, pages 66-78.

All tasks were carried out during a single testing session.

3.2.1 Subjects:

348 Children, 173 girls and 175 boys aged between 5 and 11 years 8
months (61-142 months), mean: 8.7 years (105 months, s.d. 21), for whom the first language at home was English* were individually assessed. The children attended 6 different schools in the Warwickshire area: 1 inner city, 1 rural, 2 suburban, 1 mixed-rural and 1 council estate. Children were unselected for either scholastic ability or laterality and were seen by one of two examiners in order of their classroom register. Six children, all males, were excluded from the final analyses because the skill of both hands was more than 2 sd.s below the mean of the sample as a whole. This left a total sample of N=342 (173 girls and 169 boys).

*Based on teacher's report.

3.2.2 Hand Skill
The skill of each hand was assessed using Annett's (1970) peg moving board. Each child was requested to move 10 wooden pegs one at a time, for between 3-5 trials, first with one hand and then the other, from one row of holes towards them into a second, parallel row of holes, timed in 1/10 seconds. Full procedural details are presented in Chapter 2, page 70.

3.2.3 Hand Preference
In brief, each child was observed for their spontaneous choice of preferred hand, either miming or carrying out, seven skilled actions. Refer to Chapter 2, pages 71-72, for full procedural details.
3.2.4 Nonverbal Reasoning
Each child was individually assessed using Ravens Coloured Progressive Matrices, book form. 1982 Scottish norms were used to convert raw scores into percentiles (Raven, Court & Raven, 1984). The child was asked to point to the response of their choice in order to complete a sequence of abstract shapes.

3.3 RESULTS

3.3.1 Parametric data
(i) Mean standardized scores for each hand separately in groups classified for between hand difference scores (R-L group)
Figure 3.1 gives the mean standardized scores for each hand separately for the whole sample when classified into four groups using the difference between the scores of their two hands (left hand score subtracted from right hand score); the x-axis represents children with scores of 0 or less (20% of the sample) and groups 2 to 4 as 30%, 30% and 20% proportions of the sample. These groups represent absence of bias to the right hand, and mild, moderate and strong dextrality.

Taking the left hand first, results of an ANOVA found between group differences for mean left hand scores to be highly significant (F=64.244, df:3,343, p<0.000) as was a test for linearity (F=191.758, df:1,343, p<0.000). The same analysis of the right hand for between-group differences (F=14.16, df:3,343, p<0.000) was highly significant, as was the test for linear trend (F=33.07, df:1,343, p<0.000), possibly due to the noticeable fall off in right hand skill in
FIGURE 3.1
HAND SCORES WITH R–L DIFFERENCE

HAND SCORE

\[ \bar{x}_{107.3} \sim 97.7 \sim 89.5 \]

RIGHT HAND

\[ \bar{x}_{98.6} \]

LEFT HAND

\[ \bar{x}_{89.5} \sim 18.2 \]

R–L DIFFERENCE

Ns: 66

110  101  65
those children at the left extreme of the distribution.

Of particular interest, in the light of the theory of trade offs between costs and benefits associated with strength in bias towards dextrality, was whether there were any real differences in the skill of either hand between the mild and strongly dextral children. Results of a planned paired comparison on these two groups (R-L groups 2 and 4) found highly significant differences for the left hand (t=10.13, df:343, p<.000) but not for the right (t=1.745, df:343, ns); a similar pattern of results was observed when R-L groups 2 and 3 were compared (left hand: t=5.125, df:343, p<.000, right hand: t=1.331, df:343, ns) this suggests that overall strength of dextrality may be due to poor left hand skill and not right hand bias as was predicted. Paired comparisons between R-L group 2 and 1 for each hand separately was highly significant for both hands (left hand: t=4.333, df:343, p<.000, right hand: t=4.679, df:343, p<.000) indicating that the skill of the left and right hand in those lacking any between hand bias favouring dextrality, is significantly different from mild, moderate and strong dextrals.

The distributions of left and right hand skill presented in Figure 3.1 show that as expected, the children lacking any bias towards the right hand for overall between hand differences (those at the left extreme of the distribution, R-L ≤0) have the fastest left hand and the slowest right hand skill of all four laterality groups. At the opposite side of the distribution, the between hand skill of the strongly dextrals is clearly not a simple case of reversing the hand skill pattern of those
at the left extreme. Strong right-handers have the greatest difference between their hands in skill of all four laterality groups, which is due not to the increased strength of the right hand (this stays relatively constant for all children with any bias towards dextrality) but because of a considerable drop in skill of the left hand.

(ii) Matrices Percentiles in R-L groups

Figure 3.2 gives the mean percentile scores, for each sex separately, when grouped for R-L differences. The laterality groups were defined as before. ANOVA group (4) x sex (2) comparisons revealed that the between group differences were highly significant (F=3.476, df:4,334, p=.008), as was a main effect of sex (F=6.559, df:1,334, p=.011), with the effect for group was non-significant (F=2.317, df:3,334, p=.075). No significant interactions were observed.

When the sexes are combined (Figure 3.3) for matrices percentiles and classified by group, a test of trend was found to be significantly linear (F=5.631, df:1,338, p=.018) showing a decline in ability with increasing dextrality. Thus it would appear from the results that while males consistently do better on this measure of ability than females, whatever their laterality, smaller differences are observed between the sexes among the strong right-handers, both having the lowest group mean percentile scores. Combining the sexes, planned paired comparisons between R-L groups 2 and 1 showed no significant between group differences for mean percentile scores (t=0.114, df:338, ns) as did comparisons between R-L groups 2 and 3 (t=0.644, df:338,ns).
FIGURE 3.2
MATRICES TEST PERCENTILE WITH R–L DIFFERENCE

C.P.M. PERCENTILE

BOYS

GIRLS

R–L DIFFERENCE

Ns: Males
Females

39
27

52
58

.47
.54

.31
.34
FIGURE 3.3

MATRICES TEST PERCENTILE WITH R-1 DIFFERENCE

C.P.M. PERCENTILE

R-1 DIFFERENCE
However, theoretically the most important comparisons are regarded to be between mild and strong dextrals. T test comparison between R-L groups 2 and 4 was shown to be significant for mean percentile scores (t=2.453, df:338, p=.015).

(iii) Mean standardized hand scores in three ability groups
After transformation of matrices raw scores into percentiles, the children were stratified into three ability groups on the basis of the top 25%, middle 50% and bottom 25% of the distribution. Ability groups were: 'bright' 76+ on percentiles; 'average' 26-75 and 'below average' 0-25. A computerised frequency count of percentiles for the whole sample showed the mean, median and mode to be 50, this supported the belief that ability in the sample was normally distributed.

Table 3.1 gives the actual numbers, means, and standard deviations for the standardised scores for each hand when ordered for ability group, and the mean and standard deviations for the skill between the hands (R-L score) at each ability level, sexes combined. As can be seen from the table the scores for the left hand decrease serially (get slower) from the brightest children to the dullest ability group (means: 98, 94 and 90). Mean right hand scores remain relatively flat across the three levels of intellect (108, 106, 106 bright, average and dull respectively). The loss of power in left hand skill as ability gets poorer, in combination with right hand skill which shows little change between the groups, results in the largest differences between the hands in skill (R-L 16, strongly right-handed) amongst children who are intellectually below average (mean percentiles 0-25).


<table>
<thead>
<tr>
<th>Coloured Progressive Matrices *</th>
<th>N</th>
<th>Left hand score Mean</th>
<th>s.d.</th>
<th>Right hand score Mean</th>
<th>s.d.</th>
<th>R - L score Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>76 +</td>
<td>78</td>
<td>98</td>
<td>15</td>
<td>108</td>
<td>12</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>26 - 75</td>
<td>173</td>
<td>94</td>
<td>16</td>
<td>106</td>
<td>13</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>0 - 25</td>
<td>91</td>
<td>90</td>
<td>16</td>
<td>106</td>
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<td>14</td>
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</table>

ANOVA

<table>
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<tr>
<th></th>
<th>d.f.</th>
<th>F</th>
<th>p</th>
<th>F</th>
<th>p</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>2,339</td>
<td>4.83</td>
<td>0.008</td>
<td>1.05</td>
<td>ns</td>
<td>2.99</td>
<td>0.052</td>
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<tr>
<td>Linear trend</td>
<td>1,339</td>
<td>9.60</td>
<td>0.002</td>
<td>1.27</td>
<td>ns</td>
<td>5.69</td>
<td>0.018</td>
</tr>
<tr>
<td>bright versus below</td>
<td>339</td>
<td>3.11</td>
<td>0.002</td>
<td>1.17</td>
<td>ns</td>
<td>2.35</td>
<td>0.019</td>
</tr>
</tbody>
</table>

* Right hand norms for both hands

* Hand skill in bright, average and below average ability groups: standardized scores for peg moving time.
Two separate ANOVA's were carried out (Left hand x right hand x R-L Group) in order to compare the skill of each hand separately in the four R-L groups, the results showed: a significant between group F ratio (F=4.83, df:2,339, p=.008) for the left hand, but non-significance for the right hand (F=1.05, df,2:339, ns); indicating that left hand weakness was the significant contributor to overall between hand differences and not right hand strength. Highly significant linear trends were observed for the left hand (F=9.60, df:1,339, p=.002) but not for the right (F=1.27, df:1,339, ns). Between group differences for R-L mean scores also reached the conventionally accepted level of significance (F=2.99, p=.052). The clear pattern emerging from these results is that it is the variability in left hand skill and not the right which is responsible for the inverse relationship between actual differences in skill between the hands and ability. A t-test planned paired comparison between the bright and below average ability group children for R-L, revealed that overall a significant difference is observed in between group strength of dextrality (t=2.35, df:339, p=.019) with the brightest children as a whole being less dependent on the skill of their right hands.

3.3.2 Non parametric data

(i) Hand preference with ability

Turning now to the percentage proportions of hand preference classes in each ability group. Table 3.2 gives actual numbers and percentages of all children, sexes separately, who were left-hand writers, consistently left-handed, mixed handed children and consistent
### TABLE 3.2

Hand preference in bright, average and below average ability groups: percentage of left-handed writers consistent left-, mixed- and consistent right-handers.

| Coloured Progressive Matrices: Percentiles | MALES | | | | FEMALES | | | |
|---|---|---|---|---|---|---|---|---|---|
| 76+ | 48 | 12.5 | 4.2 | 35.4 | 60.4 | 30 | 6.7 | 0.0 | 33.3 | 66.7 |
| 26 - 75 | 84 | 5.9 | 2.4 | 33.3 | 64.3 | 89 | 9.0 | 5.6 | 24.7 | 69.7 |
| 0 - 25 | 37 | 8.1 | 5.4 | 27.0 | 67.6 | 54 | 7.4 | 0.0 | 27.8 | 72.2 |
| Total | 169 | 8.3 | 3.6 | 32.5 | 63.9 | 173 | 8.1 | 2.9 | 27.2 | 69.9 |
right-handers (made no left hand choices on their hand preference assessment) when classified for ability. Of specific interest to the present study was whether there would be evidence for an increased proportion of consistent right-handers in the poorest ability group. The distributions presented in Table 3.2 confirms, for both sexes, and across all three ability bands, the inverse nature of the relationship between consistent right-handers and ability. The proportion of such children is at its lowest in the top 25% of percentiles, the 'bright' children (60.4% males, 66.7% females), and at its greatest in the bottom 25% of 'below average' intellect children (67.6% males, 72.2% females), with an intermediate incidence in the middle range of ability (64.3% males, 69.7% females). For the strong sinistrals (those with no preference for the right hand for any action), the direction of results was inconclusive, but the group itself has very few subjects.

3.4 DISCUSSION

The principal finding of this study was that extent of dextral bias was inversely related to nonverbal reasoning ability. There was a decline in ability, from left to right, across the laterality continuum. Children reduced in bias towards the right hand were the most talented and those with strong dextral dependence were found to be the least able intellectually. The between group analysis was non-significant, but was important in showing differences in ability between the laterality groups. As predicted reduced dextral bias was associated with better nonverbal ability - trend analysis showed that the loss of intellectual power, from left to right, had a significant linear function.
These findings corroborate experimentally the findings of Annett & Kilshaw (1982) and add weight to the argument by Annett (1985) that "the advantages of developing speech and language function on the left side are obtained at the cost of some handicap to right hemisphere function" (page 355).

There are at least four possible explanations for the present findings, either the action of the rs+ gene increases the chances of left-cerebral dominance for language and handedness, and when this relationship is excessive, as in the case of those carrying two copies of the rs+ gene, there is significant right hemisphere handicap (Annett, 1985); the effect is the consequence of several genes whose combined activity changes the effectiveness of some major gene; the observed differences are due to different teaching methods, or, a pathology hypothesis applies. Given that neither of the first two arguments can be substantiated until such time as genetic markers are found and the third option was not controlled for in the present study, the first and final explanations do at least allow empirically testable hypotheses. The finding of a significant relationship between reduced dextral bias and good nonverbal ability is in general agreement with previous research findings (see page 19). However, the findings with respect to the relationship between left hand weakness and right hand bias are novel in that they explore a relationship which has not been previously reported in a large population survey.

Most accounts of sex differences for nonverbal ability in the literature (see page 19) refer to a superiority in favour of males, however they are rarely observed until adolescence, and are not,
according to the Ravens test manual expected for this test. The present findings unexpectedly found that boys were significantly better than girls for nonverbal ability. These findings do present problems for the RS theory, in particular that the sex effect noted was almost certainly due to male-female differences at the left not right of the laterality continuum, which is not predicted. Thus, the present results do not support the prediction of a same sex effect in left-handers. The source of these conflicting findings has not been established.

With respect to the children at the dextral extreme of R-L differences, inspection of Figure 3.2 shows that those with excessive right hand dependency are always the least able and that this applies to both sexes alike. That strong dextral dependence can have a detrimental effect on nonverbal intelligence for both sexes, is a new and unexpected finding of the present investigation.

If the sexes are combined, the pattern of results as illustrated in Figure 3.3, are obtained. Inspection of Figure 3.3 shows that two interpretations are possible for the observed left to right linear decline in ability. Superior ability at the left side of the continuum could be explained as either pathological or reduced dextral bias. Previous evidence in the literature regarding differences for nonverbal ability between handedness groups was discussed in Chapter 1, (page 5) in terms of a pathology hypothesis. Briefly, this hypothesis suggests that the special nonverbal talents of some left- and mixed-handers is due to early developmental pathology of the left
hemisphere coupled with compensatory right hemisphere growth (the "Geschwind Hypothesis").

On the basis of a pathology hypothesis several predictions can be made from previously reported research. Two such predictions are that it would be expected that individuals with special intellectual talents and presumed left hemisphere pathology should be so as a result of poorer right hand skill than intellectually less able children, and also that such individuals should have poorer right than left hand skill generally. The alternative hypothesis proposed by the RS Theory, would be that absence of the rs+ gene, whose main role is to organise left hemisphere speech but only at some cost to right hemisphere function, is avoided in such individuals, therefore no impairment of either hand would be expected.

However, without some independent measure of the skill of each hand separately (assuming that such a measure is a general indicator of functional efficiency between contralateral sides of the brain), it would be impossible to draw any firm conclusions. It is to a consideration of the results linking the skill of each hand with between hand differences that the focus now shifts.

Right and left hand skill: Using a between groups design, Figure 3.1 reported the distribution of mean left and right hand scores when children were classified into R-L groups. Highly significant differences were found on a one-way ANOVA in the mean skill of both hands (left hand $F=64.244$, $df:3,343$, $p<.000$; right hand

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The test for trends was also conclusive for both hands emphasizing the linear relationship between skill of each hand separately across between hand differences. Inspection of Figure 3.1 clearly demonstrates that the skill of the right hand stays relatively constant with little difference being observed between mild, moderate and strong dextrals and a slight (nonsignificant) fall off in speed in those at the sinistral extreme. Overall the strongly dextral children were slightly better with their right hands than mild and moderate dextrals. There were no strong indicators that the intellectually more able children (those reduced in dextral bias) were significantly slower with their right than left hands than other children. Thus the present pattern of results supports the prediction that mild dextral bias carries advantages for ability but fails to support the pathology hypothesis predicting right hand/left hemisphere impairment. These findings provide experimental support for the suggestion of Kilshaw & Annett (1983) that strong dextrality depends on left hand weakness/right hemisphere handicap, and is associated with poor ability.

That the strength of dextral bias can have a detrimental effect upon intellectual performance, is an important point of interest for the RS Theory: theoretically, mild, moderate and strong dextrals are presumed to differ in degree of right hemisphere handicap associated with variable rs+ gene expression, therefore the most important comparisons, for Annett, are between mild (the least disadvantaged) and strong dextrals (the most disadvantaged) not between left- and right-handers. A comparison of the relative contributions of the skill of each hand to
between hand differences in mild and strong dextrals (R-L groups 2 and 4) found significant differences for the left hand but fell well short of significance for the right hand.

A similar left-hand/right hemisphere effect was found when the sample was stratified into three levels of ability based on Matrices percentile scores: bright (top 25 per cent), average (50 per cent) and below average (bottom 25 per cent). Inspection of hand skill differences in children classified by ability group (Table 3.1) showed overall that the right hand skill of bright children was slightly, but not significantly better than either average or below average ability children; for the left hand, however, there were highly significant between group differences. With regard to between group comparisons, it was found that the relative contribution of skill of each hand to between hand differences differed between bright and below average ability children: left hand skill was significantly slower in below average than bright children, but no significant differences were found for right hand skill. These findings support Annett's proposal that individual differences in right-hand skill are generally less important in determining extent of dextral bias and associations with poor nonverbal ability than are the differences in left-hand skill.

The second prediction of the "Geschwind hypothesis" - that pathology determines special intellectual talent and sinistrality, is also difficult to substantiate. All the children included in the present analysis had hand speeds within the normal range, those children who did not and were found to be abnormally slow with both hands were
excluded prior to analysis. Thus, whilst there is agreement between the two theories that it is the variability of the right hemisphere that has important implications for lateral asymmetries, there is little support for the notion that pathology determines special intellectual talent. The present findings are in line with the RS Theory’s prediction, and support the belief expressed by Annett (1985) that "bias to the right hand in right-handers depends on a handicap to the left hand" (page 355).

It should be noted however, that the pathology hypothesis has relied on hand preference as a measure of laterality and not actual hand skill. Therefore a consideration will now be made of the associations between hand preference and ability. Inspection of the hand preference distributions (Table 3.2) when classified into bright, average and below average ability groups, shows the inverse relationship between magnitude of right-hand bias and ability, for both sexes, and across all three ability groups. Whilst there was a greater proportion of females to males in all three ability levels, it is worth noting that the pattern of results showing that ability declines with increasing dextral bias was the same for both sexes. This finding is of particular interest as it fails to support any general explanation of selective pathology to explain the superior nonverbal ability of talented left- and mixed-handers (Geschwind & Galaburda, 1985; Benbow & Stanley, 1980).

As previously discussed (page 19), evidence from the pathology hypothesis has given rise to the widely accepted view that verbal abilities in left- and mixed-handers will be poor while with perceptual
and nonverbal abilities the position is reversed; such individuals are expected to show superior performance relative to other handedness groups for nonverbal abilities and a greater likelihood of being male. Thus within a pathology hypothesis it would be predicted that superior nonverbal ability would be restricted to a small sub-set of the sample. The present study found no support for such a proposal, the effect observed was present between average and below average children, as well as between bright and average.

Thus the above results lead to the suggestion that the effect of hemisphere specialization on intellectual ability is the result of a mechanism, the rs+ gene, which affects the whole of the population in broadly the same way: it carries costs for right hemisphere function the severity of which depends on whether one or two copies of the rs+ gene are present. Should this suggestion be correct then those with a double copy of the rs+ gene (the rs++ genotypes) the strong right-handers are likely to be excluded from intellectually talented groups.

This first study has attempted to both consolidate and extend existing findings by presenting new evidence. In doing so the current work has gone some way towards achieving its aim of exploring possible points of contact between the present findings and the wider literature on laterality and its implications for certain special psychological abilities. Some of the effects found in this first study will be returned to in the next section.
From the investigation of associations between nonverbal ability and laterality, attention will now turn to the distribution of reading ability and laterality in a representative sample of schoolchildren. The present work sought to test the hypothesis that an excess of poor readers will be found at dextral and sinistral extremes of the laterality continuum and fewer among those moderately biased to the right hand.
4.1 Introduction

In the previous study it was found that increasing bias in favour of the right hand was a function of a linear decline in left hand skill across the laterality distribution and not to any increase in speed of the right hand, which remained relatively stable for all degrees of dextrality (mild, moderate and strong). Poor nonverbal ability was shown to be associated with strong right hand bias - ability being the poorest for both sexes at the extreme right of the laterality continuum.

A possible explanation for this finding was suggested in terms of a factor (the hypothesized rs+ gene) which while facilitating the development of speech in the left hemisphere (and right-handedness) is only gained by handicapping right hemisphere function. Excessive right hand bias therefore, is predicted to greatly increase the risks for abilities which are generally assumed to be directed by the right side of the brain (visuo-spatial and perceptual). However, as stated in the Chapter 1 (page 13) an important issue lies in whether the complementary abilities and disabilities in language and visuo-spatial skills of some individuals arises from natural variation in the distribution of a gene (rs+) which aids the development of speech in
the left hemisphere (Annett's RS Theory) or, as some form of human pathology (Geschwind & Behan, 1982; Geschwind & Galaburda, 1985; 1987). It is possible that the inferior nonverbal ability associated with excessive dextral bias found in the previous study could be pathological in origin, however, the theme of the present thesis would argue that the majority of individuals with learning difficulties (verbal or nonverbal) arise because they represent the extremes of the normal distribution of biological differences.

In an effort to differentiate between the two alternative hypotheses, the present study has excluded any children with abnormally slow hand speeds in both hands. The crucial point for the RS Theory is that among individuals with certain special psychological abilities and disabilities both those lacking the rs+ factor inducing left hemisphere language representation (rs− genotypes) and those with two copies of the rs+ gene (rs++ genotypes) will be over represented. With particular regard to the specific deficits expected, it is suggested that absence of rs carries greater risks for abilities which depend on efficient language processing, while those with too much rs will be held back by poor processing of the visual features of written language, both are therefore expected to include an increased frequency of children presenting developmental delays in learning to read.

One of the aims of the present investigation was to replicate and expand on the findings reported by Annett & Kilshaw (1984) with regard to the inverted U relationship between reading and hand skill.
However, two differences to the original methodology should be noted:
subjects were unselected for ability; participants were children from
normal educational settings and not from clinic or undergraduate
populations.

The opportunity to additionally assess the reading of the same children
as reported for nonverbal ability, allowed further exploration of two
points implicit throughout this thesis. The first with respect to the
nature of the association between ability and laterality and the second
with respect to current distinctions in the literature between
sub-groups of poor readers.

The predominant findings in the clinical literature of a raised
prevalence of left- and mixed-handers with reading deficiencies (Orton,
1937; Naidoo, 1972; Zangwill, 1962), yet a failure to observe this same
relationship in normal populations (Rutter, Tizard & Whitmore, 1970;
Satz & Fletcher, 1987) can be explained in terms of the special
characteristics of the samples being assessed; clinic groups being only
a sub-set of the general population cannot fully represent the
variability present in normal populations - either for handedness or
ability. Such special groups are typically selected on the basis of
their ability, and often include only those individuals with learning
difficulties in spite of adequate intelligence at the exclusion of
others whose deficits are coupled with poor intellect. If this is
true, then in the light of the previous study's findings for nonverbal
ability, strong dextrals would be lost from such samples.

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Rutter & Yule (1975) found that intelligence distinguished between two sub-groups of poor readers: those who were poor readers in spite of adequate intelligence (specific reading retardates) and others who are poor readers relative to the average for their chronological age but not their intelligence (backward readers); these distinctions have obvious relevance for the present study. In order to explore further these possible distinctions it was necessary to test a large population sample who were unselected for either ability or laterality. With regard to possible contamination of results from children whose first language was not English, teachers were confident in identifying the children for whom this applied and they were subsequently excluded from analyses.

Whilst the objective of the first study was to re-investigate with a normal population study, the findings reported by Kilshaw & Annett (1983) in support of the proposal that excessive bias to the right hand was dependent on left hand weakness rather than increased right hand skill and was associated with poor nonverbal ability, this second study aimed to take a closer look at the RS Theory's hypothesis of a human balanced polymorphism with heterozygote advantage for ability by comparing relationships between reading and laterality, and the possible differences for ability and hand skill in those children at both laterality extremes.

Two measures of reading were investigated: Reading quotient (RQ), a
reading score equated for age, this is a measure of reading achievement which can be compared with the level of reading expected, on average, for other children of the same chronological age; standardized residuals (referred to as "stresids" within the text) which are calculated from the number of words read, chronological age in months and the raw score for the Ravens Matrices. By using this statistical technique it is possible to identify children whose reading ability is less than would be expected from both their chronological age and their intellectual level. Children poor on RQ but not on stresid were defined as 'backward' readers while others who were poor in relation to their intellect but not necessarily their age were regarded as 'specific reading retardates'. Previous research has investigated the possible relationship between handedness and reading ability (Rutter, Tizard & Whitmore, 1970) therefore meaningful comparisons can be made.

The present study had four main predictions which it attempted to test:

1. That the distribution of reading in a general, unselected population would follow an inverted U function;

2. For both measures of reading, RQ and stresid, alone or in combination, an increased frequency of good readers will be found among mild dextrals and an excess of poor readers at left and right extremes of the R-L differences. Planned paired comparisons will be made between mild and strong dextrals;
3. Children identified as 'dyslexic', will include a higher proportion of nonright-handers;

4. Poor readers at the dextral extreme of R-L differences are expected to be associated with weak left hand skill and lower intelligence (backward readers), while poor readers at the sinistral extreme are expected to be so in spite of adequate intelligence (specific reading retardates).

4.2 Method and procedures

Children were seen in pairs and individually assessed by two examiners working in parallel at opposite ends of a quiet room in each school. The children were seated back to back so that one could not see what the other was doing. Ordering of tasks was such that children did not hear each other on the reading test, as when one was doing this the other had headphones on and was listening to a tape recorded task.

4.2.1 Subjects

353 Children from 6 state schools participated in this study. All were seen in order of their classroom register, in whole year groups, and were not selected for either ability or laterality. As the primary purpose of the present investigation was to ask questions relevant to reading ability, children below the age of six years were omitted from the analyses as were others whose first language at home was not English. The extremely slow hand speeds, for both hands, ($\leq 2$ sd below the sample mean) led to the exclusion of a further 5 boys.
For the general analysis specifically concerned with reading a total of 313 children remained. For the stress analyses there were 150 boys and 158 girls, a loss of 5 more children due to incomplete data.

4.2.2 Peg Moving
The verbatim instructions for this task are given in chapter 2, page 70. Essentially, children were timed moving wooden pegs from one parallel row of holes to another with the encouragement to go as fast as they could. Three alternate trials with each hand were given to the younger 6-8 year old children and 5 trials for the older 9-11 year olds. In order to parallel Annett & Kilshaw's (1984) study, mean times were converted into standardised scores for age, using right hand norms for both hands, this allowed the generation of a common standardised score.

4.2.3 Hand preference
Again complete procedural details are given in chapter 2, pages 71-72. Briefly, children are observed miming or carrying out seven actions. Their recorded hand preference were subsequently classified into five groups as described by Annett (1985).

4.2.4 Nonverbal intelligence
Raven's Coloured Progressive Matrices was administered to each child. Responses were given by pointing to one of several choices. Percentiles were calculated based on the 1982 norms for Scottish children (Raven, Court & Raven, 1984).
4.2.5 Reading
Reading age and reading quotients were derived from the individual test scores of children examined on the Schonell Graded Word Reading Test (Schonell & Schonell, 1952). Standardised residuals (stresid scores) for each child derived from a multiple regression analysis (see page 75 for procedure), allowing an objective assessment of each child's reading ability within the population when age and intelligence had been accounted for.

4.2.6 Analyses
All between laterality group values, whether for hands separately or between hand difference in skill will be reported in a left to right direction.

Due to the varied criterion demanded for some analyses there are instances where the data being reported is that for 313 children but on other occasions this number is reduced to 308 by the exclusion of 5 children, all female, who lacked intelligence test scores. All children being reported upon are however, members of the original main sample of 334 children.

4.3 RESULTS
4.3.1 The sample distribution of reading
The results of this study support Annett & Kilshaw's (1984) important finding concerning the disadvantages for reading associated with each extreme of the laterality distribution. An excess of poor
readers were found at L-R intervals favouring the left hand (R-L ≤ 3) and at the right extreme (R-L > 22).

Good readers, regardless of criteria used, i.e. RQ or standardised reading score derived from age and intelligence raw scores (stresid), in combination or separately, were consistently more likely to be found among mild and moderately dextral children on a measure of between hand differences. Further analysis of the skill of the hands separately indicated that between hand differences strongly biased towards the right hand were due to a noticeable slowness of the left hand rather than to any strength in right hand skill.

4.3.2 Reading skill and hand skill differences: The relationship between the distributions

(i) Reading when measured by RQ - the whole sample

Children when classified by R-L group included at the left extreme (group 1) 18% of children with faster left than right hands or no difference between their hands for skill plus a further 6% whose bias was between 1-3 points in favour of their right hands. The next 25% of the distribution, group 2, all demonstrated a mild bias towards dextrality. Groups 3 and 4 accounted for 25% and 26% of the sample, and were moderately or strongly biased in favour of their right hands.

Between group differences on a one-way ANOVA of mean RQ's across laterality groups was non-significant.
Mean RQs were observed to fall at both extremes of the laterality distribution (R-L groups 1 and 4), with the test of trend being significantly quadratic (F=3.9453, df:1,309, p=.0479). The results indicate that the best and the worst readers are more likely to be found among mild and strongly dextral children (R-L groups 2 and 4). Highly significant between group differences were observed on a planned paired comparison between these two groups, R-L 2 and 4 (t=2.544, df:309, p=.011). This first analysis confirmed our initial prediction that poor readers were more likely to be found at each extreme of the laterality distribution and good readers in the centre.

(ii) Sex differences

The RQ data aggregated across schools was analysed as a two way (R-L X Sex) Analysis of Variance. This showed a main effect of group across subjects which was non-significant (F=2.195, df:3,309, p=.089), no effect for sex (F=0.136, df:1,309, ns) and no significant interactions (F=0.852, df:3,309, ns). This suggests that the sex of the child is not crucial to individual differences in reading progress. Figure 4.1 presents graphically the mean RQ for each laterality group, sexes separately.

(iii) Reading when measured by Standardized Residuals (stresids)

Similar patterns of results were obtained to those regarding RQs (reported above in (i)) when the criterion for reading skill was the
FIGURE 4.1
RQ with R-L HAND SKILL
child's standardized residual score (stresids). These were the standardized scores for each child derived from a multiple regression analysis as described fully in Chapter 2, page 75.

No between group differences or quadratic trend on a one-way ANOVA were significant (group: F=2.0576, df:3,304, p=.1059; quadratic: F=3.5852, df:1,304, p=.0592). Actual means across groups were: .0068, .2329, .0474 and -.1659 confirming the previous finding for RQ, that the best readers were over represented among children with a mild bias favouring dextrality and the worst among those with the strongest bias towards right-handedness.

A two-way ANOVA (R-L Group X Sex) using standardised residuals showed statistically smaller effects than that found for RQ alone, (stresid X R-L Group X Sex), (F=2.139, df:3,304, p=.095); mildly dextral children (R-L group 2) having higher reading ability than remaining groups. No other effects approached significance (sex: F=1.896, df:1,304, ns) and no significant group by sex interaction was found (F=1.220, df:3,304, ns). On a planned paired comparison between mild and strong dextrals (R-L groups 2 and 4) the previous finding for RQ was confirmed, with highly significant differences being observed (t=-2.472, df:151, p=.014).

4.3.3 Sub-groups of children with and without reading difficulties:

Their differences and similarities for laterality

Tables 4.1 (a) and (b) tabulate sub-groups of good and poor readers
<table>
<thead>
<tr>
<th>Reading Group</th>
<th>N</th>
<th>Sex Ratio</th>
<th>R-L Group</th>
<th>Hand Preference</th>
<th>Hand Skill for Peg Moving</th>
<th>Matrices percentile(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male:Female</td>
<td></td>
<td>percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>percent</td>
<td>1 2 3 4</td>
<td>Right</td>
<td>Left</td>
<td>consist. writers</td>
</tr>
<tr>
<td>1. GOOD RQ (not stressed)</td>
<td>16</td>
<td>1.0:1.0</td>
<td>13 50 31 6</td>
<td>63</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2. GOOD STRESID (not RQ)</td>
<td>16</td>
<td>0.5:1.0</td>
<td>31 31 19 19</td>
<td>63</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>3. GOOD RQ &amp; GOOD STRESID</td>
<td>35</td>
<td>1.4:1.0</td>
<td>26 34 23 17</td>
<td>69</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

F Ratio
* ns
** p = .000

Tukey-HSD
1 v 2 & 3
2 v 3
### TABLE 4.1(b)
Comparison of 2 subgroups of Poor Readers

<table>
<thead>
<tr>
<th>Reading Group</th>
<th>N</th>
<th>Sex Ratio</th>
<th>R-L Group</th>
<th>Hand Preference</th>
<th>Hand Skill for Peg Moving</th>
<th>Matrices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male:Female</td>
<td>1 2 3 4</td>
<td>Right Left consist. writers</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>1. POOR RQ (not stressd)</td>
<td>14</td>
<td>0.8:1.0</td>
<td>43 36 0 21</td>
<td>50 29</td>
<td>91 (17) 95 (15) 4 (16)</td>
<td>18 (15)</td>
</tr>
<tr>
<td>2. POOR STRESID (not RQ)</td>
<td>17</td>
<td>1.5:1.0</td>
<td>0 23 23 53</td>
<td>88 0</td>
<td>89 (12) 111 (9) 22 (11)</td>
<td>69 (24)</td>
</tr>
<tr>
<td>3. POOR RQ &amp; POOR STRESID</td>
<td>35</td>
<td>1.3:1.0</td>
<td>29 17 23 31</td>
<td>66 9</td>
<td>89 (18) 101 (13) 13 (16)</td>
<td>40 (23)</td>
</tr>
</tbody>
</table>

- F ratios: ns 6.160 5.758 21.690
- p: 0.004 0.005 0.000
- Tukey-HSD: 3 v 1 & 2 3 v 2 1 v 2 & 3 2 v 3
(good RQ but not stresid, good stresid but not RQ, good RQ and good stresid; poor RQ but not stresid, poor stresid but not RQ, poor RQ and poor stresid), their mean standardized hand scores, hands separately, difference scores together with mean CPM percentiles and sex ratios for each group.

(i) Poor, average and good readers on a measure of RQ (RQ groups: \(<88, 89-122, 123\+)

Out of a total of 313 subjects taking part in this study, 50 had RQs in the bottom 16% of the reading distribution (RQ \(<88\)), 210 children were average readers, and a top 16% (53 children) had RQ's of 123+.

Chi-square analysis found highly significant differences between reading groups when classified for R-L group ($\chi^2=13.84521, df:6, p=.0311$). The percentage incidence of poor, average and good EQ readers when classified for laterality is presented graphically in Figure 4.2. The results support, at a statistically significant level, the initial hypothesis that the distribution of good and poor readers would differ. The data clearly shows the distribution of good readers to follow an inverted 'U' function while for poor readers the trend reverses. Chi-square analysis between good and poor readers when classified for R-L group was non-significant ($\chi^2=7.57224, df:3, p=.0557$).

(ii) Poor, average and good readers predicted by both age and intelligence (stresid groups: \(<-1.0, -0.9-0.9, 1.0\+)  

52 children (16.8%) were reading at least 1 s.d. below the mean (poor
FIGURE 4.2
DISTRIBUTION OF GOOD (■—■), POOR (●—●) AND AVERAGE (▲—▲) READERS IN R-L HAND SCORE GROUPS ON RQ CRITERION.

PERCENT

R-L HAND SCORE

≤3 4-13 14-21 22+
readers), 205 (66.5%) were average, and 51 (16.5%) were good readers, reading 1.0+. Figure 4.3 presents all three stresid groups as percentages of R-L intervals and shows more clearly than the previous analysis, that group 4 is over represented with poor readers. Proportionately more good readers are observed in R-L group 2 and the smallest in group 4. Although a Chi-square analysis for reading group (3) by laterality group (4) was nonsignificant ($X^2=7.67664$, df:6, ns), significance at the 10% level was observed when good and poor readers alone were compared ($X^2=6.68830$, df:3, p=.0825).

4.3.4 Were there children in a normal population who resembled dyslexics for both severity of reading difficulty and laterality? Children in the present study who were in the bottom 16% for RQ and $\leq -1.0$ for stresids were considered a possible dyslexic group. This criterion was adopted because remediation programmes are generally only started when a child is shown to be falling behind in reading progress, for both their age and their intelligence. Using both criteria, i.e. $\leq$RQ 88 and $\leq -1.0$ for stresids, 35 children were identified. A further 35 children were good readers on both, i.e. RQ 123+ and stresids of 1.0+. Figure 4.4 gives the percentage distributions of poor, average and good reading groups across the 4 laterality intervals. A 3 X 4 between group comparison failed to reach significance ($X^2=4.21720$, df:6,ns). However, when poor readers ('dyslexics') were compared with good readers on both reading measures, no significant differences were observed ($X^2=12.56279$, df:6, p=.0505).
Figure 4.3
Distributions of good (■——■), poor (●——●) and average (▲——▲) readers in R-L hand score groups on STRESID criterion.
FIGURE 4.4
DISTRIBUTIONS OF GOOD (■ -----■), POOR (○-○) AND AVERAGE (▲----▲) READERS IN R−L HAND SCORE GROUPS ON RQ AND STRESID CRITERIA
Dyslexics ordered for intelligence and classified for laterality

As mentioned above it was considered that of all the poor readers, those who were both below what was expected for age (RQ ≤ 88) and -1.0 for stresid would be most like a typical dyslexic group. However, when the laterality distribution of this group of poor readers was looked at more closely it was evident that while the mean left hand skill, like other poor readers was poor, their mean right hand skill came in between the poor RQ and poor Stresid groups and the between hand difference mean was similar to that of average readers. However, levels of intelligence observed in this 'dyslexic' group varied enormously, ranging from almost untestable, that is 7th percentile to a high of 92nd percentile.

The percentage of dyslexics of the present study at left and right sides of the laterality distribution differed when the middle or average CPM percentile value (CPM ≤ 49) was adopted to stratify the children into above and below average intelligence. Table 4.2 shows there to be proportionately fewer bright dyslexics at the dextral extreme of the laterality distribution (R-L 22+) and a greater proportion of the bright dyslexics (CPM 50+) at the sinistral side of the distribution. In the below average dyslexic condition, an almost mirror reversal in laterality distribution was found, with an excess of dull dyslexics observed with an extreme bias to the right (R-L 2.0+) and fewer at the left side of the distribution - even though all subjects regardless of intelligence fulfilled both defining criteria.
<table>
<thead>
<tr>
<th>Reading Group</th>
<th>N</th>
<th>Sex Ratio</th>
<th>R-L Group</th>
<th>Hand Preference</th>
<th>Hand Skill for Peg Moving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Male:Female</td>
<td>percent</td>
<td>percent</td>
<td>stand. scores (SD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 2 3 4</td>
<td>Right consist. writers</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>1. BRIGHT</td>
<td>11</td>
<td>1.3:1.0</td>
<td>46 27 9 18</td>
<td>46 18</td>
<td>97 (18)</td>
</tr>
<tr>
<td>(Matrices 50+ percentile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. BELOW AVERAGE</td>
<td>24</td>
<td>1.2:1.0</td>
<td>21 13 29 37</td>
<td>75 4</td>
<td>85 (16)</td>
</tr>
<tr>
<td>(Matrices 49 percentile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

T-Test Comparisons

* p=.07
** ns
*** p=.01
of dyslexia ($Q88$ and $< -1.0$ s.d.).

No significant differences were found between dull and bright dyslexics across R-L groups on a Chi-squared analysis ($\chi^2 = 4.78629, df:3, ns$), but significant differences on a Chi-square were observed when the dull and bright intellect dyslexics were divided at the median for laterality, taking the middle score of the R-L data points as a value (so that one half of the laterality distribution lies above and one half below it) $\chi^2 = 4.71691, df:1, p=.0299$.

4.3.5 Left and right hand skill: Their relative importance for between hand differences and reading

A fixed order regression, entering the scores for each hand separately showed both to be significantly correlated with RQ over the whole sample (left hand $r=.1944, p=.001$; right hand $r=.1826, p=.001$).

Whether one hand more than the other was more important for reading progress was investigated by first, adding the scores of both hands together and entering these in the equation (i.e. the overall total score for both hands); and then re-entering the scores of each hand separately to see whether when the total score had been taken out, either hand alone made any further significant contribution to the variance. Once the variance attributable to IQ (CPM percentiles) had been taken out, a fixed order regression showed that only the total score made any further significant contribution to the variance, and this was only small ($R$ square change 2.8%, $F$ Change 10.25875, df:2,305, $p=.0015$). This tells us that while neither hand on its own is
important for reading, both hands in combination do account for a significant amount of the population variance.

As mentioned in the Chapter 1 (page 58), there are differences in opinion as to the relative importance of using reading age on its own, or in combination with intelligence, to distinguish how and whether good and poor readers might differ. The next section attempts to explore this debate.

Sub-groups of Good readers:

Table 4.1(a) previously cited, shows the relevant characteristics of all three good reading groups defined by RQ alone, stresid alone and both in combination. The children who on RQ alone achieved 123+ scores and therefore were considered good readers for their age, were also amongst the most intellectually talented of our sample (mean matrices percentile=88). A second group of children who were doing better on reading than was predicted by their intelligence (good readers for st:resids 1.0+) but not for their age (RQ) were among the dullest children (mean matrices percentile=28). A third group, were good readers on both measures, i.e. they were doing better than would be expected for either their age or intelligence, had an overall group mean intelligence just above average (58). Tukey’s test of HSD showed all three reading groups to significantly differ from each other on Ravens Matrices.

It might have been expected, bearing in mind the previous chapter's
findings of an inverse relationship between intelligence and laterality, that the three good reading sub-groups might also differ for hand skill characteristics. However, although variability was noted for left, right and between hand skill differences between the groups, none were significantly so. None of the good reading groups had poor hand skill for either hand. Left hand scores varied between 97-103, right hand between 108-112 and R-L differences, 8-11, which while being smaller than the general average of 13, is not significantly different and indicates that in combination the good readers in our sample are more likely to be found in R-L group 2. This would include children with hand skill differences slightly favouring the left hand, those with no difference between the hands, together with others having mild dextral bias.

(ii) Sub-groups of poor readers
When poor reading groups were analysed for intelligence, based on poor RQ alone (RQ \( \leq 88 \)), on stresids only (\( \xi \geq -1.0 \)) or on both, all three differed significantly from each other on Tukey's test of HSD, see Table 4.1(b). The RQ only poor readers were considered to be of below average intellect (matrices \( \leq 18 \)), while the stresid only group were considerably above average (69) and poor readers both for age and intelligence had a mean of 40 for Matrices percentiles. In spite of considerable differences in intelligence, the left hand scores of poor readers as found with good reading groups, showed no significant between group differences; where they did differ from the good reading groups was that the poor reading children were all characterised by
weak left hand skill (left scores: 89-91). However, the strength of right hand skill did vary according to which criterion was being adopted for the poor reading groups. Low RQ children alone showing right-hand weakness while stresids only readers being especially skilled with their right hands. These differences obviously made an important contribution to between hand differences for both groups, with RQ only group being mildly dextral and stresids strongly biased towards right-handedness (R-L 4 versus 22).

All poor reading groups were noticeable for the poor skill of their left hands but only this sub-group of poor readers with reduced shift towards dextrality were of low intelligence and had weak skill of both hands. The distribution of all three poor reading groups when ordered for R-L group is presented in Figures 4.2 and 4.3.

(iii) Were there children in a normal population who resembled a 'clinic' group of dyslexics for both severity of reading difficulty and laterality?
A major question of interest for the present study's purposes, was whether within normal school environments there were children with similar characteristics to a clinic group of dyslexics, in that they were poor readers in spite of adequate intelligence and included a higher prevalence of non-dextrals. In order to get at this question the dyslexic group, poor on both RQ and stresid, were divided by intellect into bright or below average groups (蛆49 versus 50+ for percentiles). Comparisons of each hand separately showed neither group
to differ significantly for right or left hand skill

(\text{left hand} t = 1.89, df:33, p = .07; \text{right hand} t = ns) with
intellectually bright children being much faster than below average
intelligence children with their left hands, resulting in smaller
between hand differences indicative of a distribution reduced in bias
towards right-handedness. Highly significant between group differences
were found for between hand differences (t=2.60, df:33, p=.01).

Table 4.2 gives percentages in R-L groups of bright and below average
intelligence dyslexics, and shows that the most sinistral group were
over represented with bright dyslexics (46%) and the most dextral group
with dull dyslexics. It is suggested that these results go some way to
explain the heightened incidence of left- and mixed-handers among
clinic groups of dyslexics. The bright dyslexics in the present study
(although it is accepted that the criteria used may not be as stringent
as that employed for clinical purposes for reading difficulty) does
follow the classic format of poor reading, adequate intelligence and an
excess of nonright-handers).

4.3.6 Hand preference – an adequate measure of poor reading ability?

When the sample were tested for ability and then classified for
preferred hand, no statistically significant differences were
observed. This was a consistent finding when consistent right-handers
were compared with children who were either right or left handed
writers but mixed for other preferences; for consistent right-handers
versus nonright-handers or across the seven preferent classes described
in Annett (1985). Rather than posing any difficulty for the theory it confirms a belief held for some time, that hand preference is of itself only a general indicator of underlying actual hand skill.

Evidence to support such a notion comes from the present study in which no difference was found between right handed writers who were left preferent for other actions and pure left handers on a measure of reading quotient (both groups had a mean RQ of 108). However, when unsuccessful readers were looked at in isolation (the dyslexic group for whom intelligence was also taken into account as a predictor of reading ability) a higher proportion (46%) of the intellectually bright children were sinistral rather than strongly dextral. The opposite trend applied for the dull dyslexics, a higher prevalence of their total were strongly dextral (75%). When writing hand was assessed, left hand writers accounted for 18% of the intellectually bright dyslexics and 4% of the intellectually dull.

4.4 DISCUSSION

In support of previous findings (Annett & Kilshaw, 1984), the present study has found, for several separate analyses, an inverted U relationship between reading ability and hand skill differences (R-L) supporting the hypothesis of a balanced polymorphism with heterozygote advantage for ability (Annett, 1972; 1985). These findings held regardless of whether the measure for reading was RQ (reading ability standardised for age) or when stresids were used (reading as predicted for intelligence) in every analysis. The evidence suggests
that the reading ability of those at the peak of the distribution
(children with a mild degree of dextral bias) was superior to those at
both extremes; while an excess of poor readers were found at both left
and right laterality extremes. The present results are unique with
respect to associations between reading ability and strong dextrality
in children from normal educational settings, in that they suggest a
relationship between reading deficit and strong right-handedness that
is not generally reported.

As was also found in the first study, it is the contribution that the
left hand makes and not the right which holds important implications
for hand skill differences, which is as would be expected if cerebral
dominance for speech is bought at some cost to right hemisphere power.
When the variance both between and within R-L groups was looked at more
closely in the present investigation, an important observation was
noted. Although when taken as a whole the sample variance (s.d.) for
the left hand was greater than that of the right, if within group
variance for each hand is looked at we can see that neither hand
differs significantly, therefore it is concluded that the sample
variance difference is due to between group differences which is based
upon between hand differences and thereby right shift.

Contrary to the first study, which noted a significant sex difference
in favour of males for nonverbal ability, no sex differences have been
found in the present study for reading and no interactions between
laterality group, reading and sex. This null sex difference finding in
prevalence of reading difficulties was contrary to several studies reporting more males than females with reading problems (Rutter & Yule, 1975; Annett & Kilshaw, 1984). The lack of interaction between the three variables (laterality, reading and sex) might however, provide a possible clue that in normal population samples separate processes underly sub-types of poor readers. As previously noted (page 41) there is a strong suggestion that while poor intelligence might co-exist with deficits in reading there are other poor readers who have learning difficulties in spite of adequate intelligence.

As Annett (1985) has pointed out, there are several ways of accounting for the conflicting results reported in the literature of a lack of relationship between handedness and ability, the raised prevalence of left- and mixed-handers with reading problems and the typical sex difference effect. The variation in criteria used to define poor readers (1 s.d. below the mean in the present study in a total population sample of 313 children) 2 s.d.s below the mean, 28 months below their chronological age on tests of reading accuracy and comprehension in a survey of 2334 children (Rutter et al, 1975), and subsequently re-classified into 1) specific reading retardates; 2) intellectually retarded and 3) a combination of 1 and 2 - children who were both intellectually retarded and had specific reading difficulties. The educational tests used (the Schonell for present purposes, the Neale for the Rutter et al Isle of Wight survey), differences in methods used for assessing handedness (many studies of laterality have almost exclusively relied on self reported hand
preference and made comparisons between left- and right-handers), when
the important measure according to Annett is actual hand skill.

A secondary aim of the present study was to examine the experimental
findings generated here in the light of current distinctions between
specific reading retardates and backward readers, and to clarify the
suggested dichotomy between those having too little of the hypothesised
rs+ factor and those having too much, for reading ability. The present
study also served to judge the speculation expressed by Annett (1985),
that strongly dextral poor readers may resemble backward readers (in
that they would include children with slow left hand times, and a
higher frequency of rs++ genotypes) and sinistral poor readers specific
reading retardates as described by Rutter, Yule & Tizard (1970). The
language problems of the sinistrals, more likely rs-- genotypes, are
thought to be intrinsically organisational in nature due to the
difficulties of programming coherently speech circuitry within a large
multi-faceted brain which may be held back by inefficient communication
links between input and output information and not to functional loss
for either hemisphere. Thus it was predicted that sinistral poor
readers would have good skill of both hands.

In order to differentiate between these two possible sub-groups of poor
reader, the present study manipulated RQ and stresids so that further
investigation was possible. An obvious problem for comparisons is the
incompatibility between Rutter et al criteria and those employed in
the present study. However, after due consideration it was felt to be
an acceptable comparison, if for the present study, specific reading retardates, backward readers and dyslexics were discussed separately. Thus it would be reasonable to assume that between both studies at least some similarities of incidence would be found.

In terms of the skill of each hand for poor readers: It was found that poor reading ability, whether measured by RQ, stresid or dyslexic criteria, all tended to have slow left hand times relative to average or good readers. Therefore, the overall difference between the hands in skill depended on variability of right hand performance. In view of the assumed contralateral relationship between hand and hemisphere function it is of interest to note how the skill of each varied between the different groups of poor readers. Two such groups, the specific reading retardates (poor on stresid alone) and low intelligence dyslexics (poor on both stresid and RQ, with Matrices \(<49\), their between hand differences were large, indicating excessive dextral bias (R-L 22 and 17, specifics and backward readers respectively).

However, the contribution of the skill of each hand to the overall between hand difference was not the same. The 'specifics' were biased towards dextrality because of a weak left hand coupled with fast right hand skill, while the below average intelligence 'dyslexics' between hand difference was primarily due to the slowness of their left hands. This is in contrast to the below average intelligence poor readers on RQ alone (Matrices \(\geq 18\) who qualified for the description 'backward' readers, who showed little difference in skill between the hands.
because right as well as left hands were poor on skill. As these children included a high proportion of left- and mixed-handers due to the poor skill in both hands (and both hemispheres), the question invariably arises as to whether they were pathologically left-handed. The suggested relationship between strong dextrals and backward readers and sinistrals and specific reading retardates by Annett (1985) has not been borne out by the present results. Clearly, the observed pattern of results was in the opposite direction with specifics being strongly dextral and backwards being reduced in right-hand bias.

The only group of poor readers who did not have left hand weakness were the dyslexics (poor on RQ and stresid) who were intellectually bright (Matrices 50+). Their between hand differences were R-L 3, indicating a mild degree of dextral bias and therefore confirming the initial prediction. While the major factor for all except this one poor reading group was undoubtedly weak left hand skill/right hemisphere function, the deficits of the bright dyslexics may be argued to be quite different in nature.

Despite the consistent failure in the literature to find any relationship between reading deficiency and handedness in normal populations, the present study, by employing actual skill of the hands, has shown consistently that poor left hand/right hemisphere function is implicated in reading deficits. The good readers in the present investigation were uniform in their reduced dextral bias for between hand differences. The finding of significant differences in reading
ability between mild and strong dextrals is novel in that it explores a relationship which has not previously been noted. Table 4.1(a) clearly shows that the three groups of good readers, on RQ and stresid alone or when combined, had relatively good skill in both hands. The major point that arises from this study is that successful reading requires the involvement of both hemispheres and hence both hands.

Rutter & Yule (1975) indicated that three times as many boys to girls were specific reading retardates, while Annett & Kilshaw (1984) found similar, if slightly increased ratios of 5.5:1 males to females, but 1.8:1 in strong dextrals. In the present study no significant sex differences were observed for the sub-groups of poor readers: Specifics 1.2:1; backwards 1.3:1; dyslexics 1.5:1, dull 1.2:1 or bright 1.3:1.

This second study also served as a replication of the previous study, in that the predicted reading ability of strong dextrals (reading predicted by both age and nonverbal reasoning), was shown to be poorer than absent, mild or moderate dextral groups (X stresid values when classified for R-L group were: 0.01, 0.23, 0.05 and -0.17, R-L groups 1, 2, 3 and 4 respectively).

One of the most difficult problems to manage in this research, and noted by Rutter et al, has been that subjects can be both generally backward readers and specific reading retardates at the same time. It became evident from a frequency count of CPM values that many of the
present study's group of specifics were also below average for intelligence, even though this factor is an important predictor of expected reading ability. Of the 17 children belonging to the stresid only poor reading group (specific reading retardates) in the present study, 7 (41%) were below average for intellect (CFM \( \leq 50 \)) while the remaining children were in the top 25% band for intelligence, the latter thereby serving to obscure the prevalence of intellectually less able, 'specific' readers.

Whilst, as suggested by the findings of Geschwind & Galaburda (1985), there was evidence in the present study that left- and mixed-handers were particularly vulnerable to reading difficulties, a closer examination of this group showed that they were in fact made up of two sub-groups with different characteristics. One group were those who were poor readers on the basis of RQ alone (and had poor actual skill in both hands), and a second group who were dyslexic (poor on both RQ and stresid) but who had superior intellect. This latter group of poor readers comply very neatly with the profile expected of Annett's typical rs-- genotype. Their left hand skill is proficient and their intellect is good, which is as would be predicted on the basis of the previous study's findings of an association between left hand skill/right hemisphere handicap and nonverbal reasoning ability. In short they correspond very well with the expectations raised in the clinical literature for left- and mixed-handers who are poor readers. These findings indicate that the relationship between poor reading and left- and mixed-handers might be more subtle and complex than had
previously been assumed.

The description of the dyslexic, the focal point of interest in much of the reading research, as an individual reading below that which would be expected for their intelligence may well not be sufficient in itself to detect subtle differences on measures of laterality, between those of dull and superior intellect who on traditional criteria would be assumed to be a homogeneous group. However, this is of little practical use in itself unless it can be demonstrated that stratifying for intelligence extends our understanding of the underlying etiology of dyslexia.

The findings of the present study are in agreement with Annett (1985) in that: excessive bias to the left hemisphere is associated with motor slowness of the left hand and poor right hemisphere function. Annett's research has mainly been concerned with investigating relative advantage and disadvantage for intellectual ability being associated with presence or absence of a single gene the rs+ with the principal hypothesis that heterozygotes (rs+- genotypes) would be less at risk to disadvantage for ability. The main findings of the present study consistently support this hypothesis: the distribution of good and average readers, however defined (RQ and stresid alone or in combination) followed an inverted U function.

The results of the present study are considered to be informative in that they suggest several clues as to the nature of the relationship
between reading ability, intelligence and lateral asymmetries. However, the concern so far has been with distinguishing general differences between sub-groups of good and poor readers; the next phase of this research is to explore the bases of these differences experimentally in order to examine the possibility that the distinction between phonological/dysphonetic dyslexics and surface/dyseidetic dyslexics is relevant to the distinction between those having too little and those having too much bias to the left hemisphere and right hand.
CHAPTER FIVE

Acoustic-phonological and visual processing of written language: an investigation of a possible laterality effect

5.1 Introduction
The preceding study replicated the inverted U relationship between reading and laterality reported by Annett & Kilshaw (1984). For both RQ and stresid more poor than good readers were found at opposite ends of the laterality continuum and fewer in the middle of the distribution (expected to include a greater proportion of heterozygotes, rs+- genotypes). An explanation for this finding was offered in terms of a left hemisphere effect for those lacking the rs factor (rs-- genotypes), the poor readers at the left of the distribution and a right hemisphere effect in poor readers carrying two copies of the gene, (the rs++ genotypes) more likely in those children at the extreme right for laterality differences. The crucial point is that while both sub-groups were poor readers the nature of their difficulties may be different. If this assertion is correct, then it should be possible to examine experimentally the specific disabilities associated with the two extremes of the distribution, and to explore possible points of contact between this work and the wider literature on developmental and acquired reading disorders.
As previously discussed (page 45) evidence from normal schools has identified children who lack the skills necessary to discriminate between sounds such as 'fun', 'bun', and 'pin' while others have weaknesses in processing the visual features of words. Neither group is regarded as pathological yet both are likely to be delayed in reading progress (Bryant & Impy, 1986).

The primary aim of the present two experiments was to expand the Annett & Kilshaw findings by exploring the bases of such differences experimentally. A refinement of the original methodology was made: the present sample did not include subjects drawn from either clinic or undergraduate populations. This choice of a representative sample of school children from normal schools was made in order to provide an adequate test of Annett's hypothesis of a human balanced polymorphism with heterozygote advantage for ability. With clinic samples the association between pathology and laterality is invariably high and the danger exists of ascribing observed error patterns to abnormal, rather than to normal variability.

As noted in the Chapter 1 (page 8) one of the most powerful arguments to account for the raised prevalence of language difficulties in left- and mixed-handers has been the "Geschwind Hypothesis", which proposes that selective left hemisphere pathology is compensated by superior right hemisphere visuo-spatial skills (Geschwind & Galaburda, 1985; Benbow, 1986). The results of the previous study did partially support such a hypothesis, there were children reduced in dextral bias who were poor readers (as predicted by I.Q. and age) as well as being
bright for nonverbal reasoning ability, generally presumed to be at the
direction of the right hemisphere.

It is argued however, that while both Geschwind and Annett's models can
account for the observed language-left hander effects, Geschwind's
model is less satisfactory as such effects are also noted in normal
subjects and in the right-handed. Annett's counter argument rests on
the premise that: 'the complementary abilities and deficits in
language based versus visuo-spatial skills arises from natural
variation in the distribution of a gene (the rs+) which aids the
development of speech in the left hemisphere'. It seems unlikely that
as a general rule brain pathology would co-exist with intellectual
talent in normal individuals, and even more improbable that all left-
and mixed-handers have abnormal brain organisation. What does seem
more logical is that while the difficulties for a few extreme cases may
be pathological in origin, the majority of children with educational
deficiencies represent the extremes of the distribution of normal
differences of both cerebral specialization and ability. The finding
of an excess of poor readers at the dextral end of the laterality
continuum does not support a pathology hypothesis. It is unique in
that it presents a relationship between ability and handedness in
normal children which has not previously been reported.

As previously discussed (page 51) evidence from the memory domain
suggests that distinctions between the articulatory loop and
visuo-spatial sketch pad may be of importance to the long standing
observation in the reading literature of individual differences in
dependency on phonological and visual processing strategies. Experimental manipulation typically reports that similar sounding sets of stimuli are less well remembered than dissimilar sounding items by good readers, but not by poor readers; phonologically nonconfusable items are generally no better recalled than confusable ones in children with known reading difficulties (Baddeley, 1986). A second aim of this investigation addresses the question of whether inadequate phoneme discrimination and visual memory for words could be a means forward in discriminating between one group of poor readers who are predominantly whole word or orthographic readers and another who are over dependent on speech based phonological encoding.

Individual differences studies between good and poor readers suggest that poor readers compared with successful readers, do have a poor explicit awareness of phonology. The role of verbal encoding in the inferior performance of failed readers has been extensively investigated by such writers as Bradley & Bryant (1978); Liberman and colleagues (1974; 1977; 1980); Brady, Shankweiler & Mann (1983) and Snowling (1983) culminating in considerable evidence that some poor readers are found lacking in such skills.

The two experiments to be reported upon in the present study sought to re-examine, with a sub-set of the originally assessed children plus an extra class group, the effects of several types of stimuli, previously reported to have been of importance in distinguishing between good and poor readers. Three measures were investigated: confusable versus nonconfusable sets of words; detecting rhyme from nonrhyming stimuli;
choosing the correct word from a pair with the same sound but different spelling (homophones) in order to complete a spoken sentence.

The multivariable style of experimentation in the present experiments, as with the previous study, allows for interactive effects to appear. Any interaction between experimental variables will be noted with interest as the range and combination of measures has not previously been used in a single investigation.

Thus the present study set out to test the general hypothesis that unlike previous studies which have failed to find laterality effects in normal populations, children who show a double dissociation between phonological and orthographic (visuo-spatial) processing - poor at one and good at the other, and vice versa, are more likely to be found at both extremes of the continuum of R-L differences. Specifically, children with poor phonology but good visuo-spatial ability are likely to be those with too little of the factor inducing left hemisphere speech, while those with good phonology but poor visuo-spatial skills might be those with too much of this factor, at the left and right extremes of the R-L continuum, respectively.

The two experiments reported in this chapter are for two groups of children who differ for age. Individual assessments were carried out for the first experiment while children were tested in whole class groups for the second. There were standard assessments as for the main sample for peg moving, hand preference, Ravens Coloured Progressive Matrices and the Schonell (shortform) Graded Reading Test for the
children of experiment 1 only. Only additional tasks specific to the present two experiments will now be described in full.

5.2 Method and Procedures

EXPERIMENT 1. RHYMING ABILITY

5.2.1 Subjects

55 Primary school children (25 males and 30 females, age range 62-96 months, mean 82 months, sd. 7.0) from two state schools in Warwickshire participated in this study. All had English as their first language at home. No selection for ability was made with children being seen in pairs in order of their classroom register.

5.2.2 The task and its procedure

The examiner gave the rhyme test as instructed by Bradley (1980) using the two series of words in which either the middle vowel, or final consonant was varied. All but one of the words shared a common phoneme and the child, from its spoken presentation had to identify the odd one out (the sound that did not rhyme). The method was as suggested by Bradley (1980) pages 2-8.

5.3 RESULTS

Two measures of ability to rhyme will be reported upon in these results. The first 'rhymeage' is the standardised residual score resulting from a regression of raw rhyme scores (number correct) on the Bradley task and chronological age (CA). The second, 'CPMrhyme' is the standardised residual from a multiple regression including CA,
nonverbal reasoning (IQ) with rhyming raw score as the dependent variable. The question of particular interest was whether poorer rhyme discrimination performance would be more frequently found among non-dextrals than dextrals.

(i) The association between reading ability and sensitivity to rhyme
Significant Pearson correlations were found between ability to rhyme, predicted by age ($r=.3405$, $n=55$, $p=.005$) and when age and IQ are controlled ($r=.3764$, $n=55$, $p=.002$) with reading. This supports the basic finding of Bradley & Bryant (1983) that being able to distinguish between sounds at the level of the single phoneme is predictive of successful reading progress.

(ii) Nonparametric data: Ability to rhyme and hand preference
The sample was divided into two groups, those with negative standardised residuals (poor at the task for their age), and those who were good at the task (positive standardised residual scores) and then assessed for hand preference. Table 5.1 shows the numbers of cases and the distributions of hand preference, for consistent right and mixed- and left-handers combined at each ability level. The question of interest is whether there is an increased proportion of nonright-hand preferent children in those who are poor at rhyme discrimination. The proportion (%) of nonright-handers was shown to be greater in the -ve scoring group (those who were poor at detecting the 'odd one out') than in the +ve scoring group (those who were good at this task) 40.9% and 21.9%).

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TABLE 5.1: Good and poor rhyme discrimination for age in right and nonright preferent children (N=55) Children aged 6yrs+ Home language English.

<table>
<thead>
<tr>
<th>Hand Preference Class</th>
<th>n</th>
<th>%</th>
<th>Standardized Residuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistent right</td>
<td>13</td>
<td>59.1</td>
<td>-ve scores</td>
</tr>
<tr>
<td>(Class 1)</td>
<td></td>
<td></td>
<td>0 -highest</td>
</tr>
<tr>
<td>Mixed and Left</td>
<td>9</td>
<td>40.9</td>
<td></td>
</tr>
<tr>
<td>(Classes 3-8)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

\[ X^2 = 1.61959, \text{ df:} 1, \text{ ns.} \]
The relationship between ability level and consistent right-handedness being the converse; 59% -ve scores and 79% +ve scores.

The pattern of results was identical when the same analysis was carried out for 'cpmrhyme': Table 5.2 shows a higher proportion of nonright-handers are more likely to be worse at this task than good at it (38% -ve scores and 23% +ve scores); with the reverse trend being observed in consistent right-handers (62% -ve scores and 76% +ve scores). Chi square analysis did not achieve statistical significance for either analysis ('rhymeage' $X^2$ =1.61959, df:1, ns.; 'cpmrhyme' $X^2$ =0.77244, df:1, ns.). The results indicate that as was predicted, a reduction in right-hand bias is associated with greater risk for poor rhyme discrimination ability.

(iii) How relevant is laterality to rhyming ability?

The experimental findings in the previous section have demonstrated that, by using ability as a measure, it is possible to show that among non-dextrals the accuracy of phonological discrimination is generally less good. However, a parallel question might be to ask whether classifying for laterality and testing for ability would show lower ability scores among those with the smallest between hand differences. Also can it be shown that skill of one hand is a more powerful predictor of phonological awareness than the other, or are both important?

A fixed order regression including CA, IQ and RQ as predictors of
TABLE 5.2: Good and poor rhyme discrimination for age and intelligence in right and nonright preferent children (N=55) Children aged 6yrs+ Home language English.

<table>
<thead>
<tr>
<th>Hand Preference Class</th>
<th>n</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistent right</td>
<td>13</td>
<td>26</td>
<td>61.9</td>
</tr>
<tr>
<td>(Class 1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed and Left</td>
<td>8</td>
<td>8</td>
<td>38.1</td>
</tr>
<tr>
<td>(Classes 3-8)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CPM Rhyme
Standardized Residuals
-ve scores 0 -highest

\[ X^2 = 0.77244, df:1, ns. \]
rhyming ability (now based on raw scores for this task) showed age to account for a massive 53% of the change in R square value (p<.000). Reading quotient accounted for a smaller but still significant amount of R square change, 6% (p=.006) which confirms Bradley & Bryant's suggestion that ability to rhyme is predictive of later reading progress. Only intelligence failed to make any significant contribution to ability to rhyme (R square change 1%, p=.1847).

Repeating the fixed order regression but replacing RQ with R-L score replicated the previous findings for both age and intelligence. Additionally, the R square change was significantly increased by a further 4% with the inclusion of R-L scores (p=.0330). The relative contribution of each hand separately to rhyming skill was investigated on a repeated measures MANOVA, both for 'rhymeage' and 'cpmrhyme'. The two measures of rhyming skill were recoded into two groups of poor and good discriminators and compared for between hand differences in skill (R-L).

For 'rhymeage' poor ability children were the bottom 40% of the distribution (all scores up to and including -.1, -1.85 s.d.) and for 'cpmrhyme' the lowest 33%, all scores up to and including -.5, -1.94 s.d.). In both cases the children worst at the task had smaller between hand differences (were reduced in dextral bias) than the more able. Actual mean differences between poor and good rhyming ability subjects on 'rhymeage' was 6.2 against 14.8 and for 'cpmrhyme' 5.3 versus 13.0. Left hand skill between ability groups was shown to vary
much more than for the right hand, although not significantly so, but is still important to note because it again implicates the skill of the left hand in intellectual variability rather than the right (see chapters 3 and 4). Evidence that a single mechanism may underlie individual differences in rhyming ability is indicated by the significant interaction between the rhyme measure, ('rhymeage' x R-L differences, F=4.10, df:1,53, p=.048). No significant interaction was found between the 'CPMrhyme' x R-L scores (F=3.75, df:1,53, ns.)

(iv) Are there inter-relationships between phonology and laterality when age and intelligence are controlled?

A Pearson correlation between R-L scores, 'rhymeage' and 'cpmrhyme' was significant (r=.2517, n=55, p=.032; r=.2638, n=55, p=.026 'rhymeage' and 'cpmrhyme' respectively). The question of whether poor and good rhyming children differed for laterality was approached by comparing children with negative scores (poor ability) and those with no difference or positive rhyming scores (good ability) for R-L differences. The prediction, that childrens' ability would be poorer in those at the left side of the laterality distribution than those biased to the right, was confirmed by the following: a t-test was carried out to investigate any significant between group differences when both age and intelligence was controlled for. Between group differences were significant (t=2.02, df:53, p=.049).

A very basic analysis of how rhyming ability as predicted by age was distributed across laterality groups is presented in Table 5.3(a). A
one-way ANOVA was conducted, group means were: -.45, .14, .26 and -.10, R-L groups 1-4 respectively. Table 5.3(b) shows that the poorest ability is in children at both left and right extremes of the laterality distribution, indicated by their negative scores. Positive scores indicate superior ability at the task. Between group differences and quadratic terms were non-significant
\[ (F=1.3069, \text{df}=3,51, \text{ns}) \]
\[ (F=3.1455, \text{df}=1,51, p=.0821) \]

Some support to Annett's hypothesis that the most able children will be less biased to the right hand as a group (i.e. because of carrying only one copy of the rs+ gene, not two). The inverted U function of the distribution of rhyming scores supports the RS Theory's hypothesis that populations are 'balanced' for ability with the majority (the heterozygote, rs+ genotype, those with a mild/moderate degree of right hand/left hand bias) being more advantaged in relation to those at both left and right extremes of the laterality continuum. Clearly children least able to distinguish between rhyme and nonrhyming sounds in the present study, were more frequently found at the left extreme of the laterality distribution and noticeably absent in the central and dextral portion of the laterality continuum.

Repeating the same analysis for the 'cpmrhyme' measure showed no significant between group differences \[ (F=1.3794, \text{df}=3,51, \text{ns}) \] but a slightly increased strength of quadratic term \[ (F=3.2466, \text{df}=1,51, p=.0777) \], which was significant on a one tail criterion. The between group distribution of rhyming scores being -.48, .14, .26 and -.10 demonstrating that by controlling for intelligence children with the
### TABLE: 5.3 Rhyming correct when controlled for age\(^{(a)}\) and I.Q.\(^{(b)}\) in laterality groups - Sexes combined.

<table>
<thead>
<tr>
<th>R-L GROUP</th>
<th>n</th>
<th>(a) Age No. Correct</th>
<th>SD</th>
<th>SE</th>
<th>(b) I.Q. No. Correct</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>-.45</td>
<td>.9</td>
<td>.3</td>
<td>-.48</td>
<td>.9</td>
<td>.3</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>.14</td>
<td>.8</td>
<td>.2</td>
<td>.14</td>
<td>.8</td>
<td>.2</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>.26</td>
<td>.8</td>
<td>.2</td>
<td>.23</td>
<td>.8</td>
<td>.2</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>-.10</td>
<td>1.3</td>
<td>.4</td>
<td>-.10</td>
<td>1.3</td>
<td>.4</td>
</tr>
</tbody>
</table>

**BETWEEN GROUPS**  
\( F = 1.3069 \) df: 3, 51, \( p = .2823 \)  
\( F = 1.3794 \) df: 3, 51, \( p = .2596 \)

**QUADRATIC TERM**  
\( F = 3.1455 \) df: 1, 51, \( p = .0821 \)  
\( F = 3.2416 \) df: 1, 51, \( p = .0777 \)

**PLANNED PAIRED COMPARISON BETWEEN R-L GROUPS 1 AND 2**

\[ t = -1.546 \] df: 51 \( p = .128 \)  
\[ t = -1.658 \] df: 51 \( p = .103 \)
poorest ability have an increased probability of being nondextral
(Table 5.3(b)). Planned paired comparisons on both measures of rhyme
and R-L groups 1 and 2 (those with the least and mildest degree of
dextral bias) were non-significant for rhyme as predicted by age
('rhymeage' t=1.546, df:53, ns), and non-significant for
ability as predicted by both age and intelligence ('cpmrhyme
t=1.658, df:53, p=.103).

(v) Is sensitivity to rhyme independent of reading ability or sex?
In order to obtain some measure of the rhyme discrimination skills
between good and poor readers and between the sexes when the sample
was classified for R-L group, a 4 x 2 x 2 ANOVA was computed (R-L
group x Sex x good, RQ 105+, and poor, RQ <104, reading groups). The
results are recorded in Table 5.4 together with the number of subjects
in each R-L group, their mean scores correct for rhyme discrimination,
the mean rhyming score correct sexes separately, and the mean rhyming
scores correct for both reading groups. The results observed showed a
highly significant main effect (F=2.957, df:5,49, p=.023), with reading
accounting for a major proportion of the variance (F=10.126, df:1,49,
p=.003). No other effects approached significance (F=1.370, df:3,49,
ns; F=0.007, df:1,49, ns - group and sex respectively). There were no
indications that laterality, sex or reading interacted in any way with
rhyming ability. Details of a second (4 x 2 x 2) ANOVA, (Groups x Sex
x Reading group) using 'cpmrhyme' as a measure of rhyming ability,
again showed a massive effect of reading but none for either laterality
or sex (reading F=9.600, df:1,49, p=.004) suggesting that while reading
**TABLE: 5.4**

Rhyming correct (as predicted by age alone) when classified for R-L group, sex and reading group. Poor readers defined as having a RQ ≤ 104 and good readers RQ 105+

<table>
<thead>
<tr>
<th>R-L GROUP</th>
<th>n</th>
<th>X Rhyme score correct</th>
<th>Males</th>
<th>Females</th>
<th>Reading Group Poor</th>
<th>Reading Group Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>- .45</td>
<td>- .05</td>
<td>- .94</td>
<td>- .65</td>
<td>- .22</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>+ .14</td>
<td>- .11</td>
<td>- .39</td>
<td>- .11</td>
<td>+ .55</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>+ .26</td>
<td>- .00</td>
<td>- .34</td>
<td>- .22</td>
<td>+ .54</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>- .10</td>
<td>- .06</td>
<td>- .16</td>
<td>- .75</td>
<td>+ .55</td>
</tr>
</tbody>
</table>

**MAIN EFFECTS**

- **F** = 2.957 df: 5,49, *p* = .023
- **R-L GROUP** **F** = 1.370 df: 3,49, ns.
- **SEX** **F** = .007 df: 1,49, ns.
- **READING GROUP** **F** = 10.126 df: 1,49, *p* = .003

No significant interactions.
was associated with laterality the sex of the child was unimportant.

When laterality (R-L scores) was recoded into children with between hand differences of 39 or less (i.e. all degrees of sinistrality compared with those with no difference and all degrees of dextral bias) for rhyme discrimination, mean scores were in the predicted direction, with nonright-handers for both measures of rhyme having negative (poor) mean scores and the remainder of the laterality distribution have positive (better) mean scores ('rhymeage' nonright-handers mean: -.4545 versus dextrals .1159; 'cpmrhyme' nonright-handers mean: -.4818 versus dextrals .1114). Paired group comparisons were, on a one tail criteria significant, indicating that results were in the direction predicted theoretically ('rhyme' t= -1.75, df:53, p=.086; 'cpmrhyme' t= -1.85, df:53, p=.070).

When the two most extreme laterality groups were compared (R-L <39 and 63+, sinistrals versus strong dextrals) on both measures of rhyme, the results confirmed previous trends. Those at the left side of the distribution were less able to make accurate rhyme discriminations than those at the right extreme ('rhymeage' mean: -.4545 vs .1375; 'cpmrhyme' -.4818 vs .1437) - neither analyses were significant on a test of t ('rhymeage' t=1.76, df:25, p=.090; 'cpmrhyme' t=1.81, df:25, p=.082).

The association between ability to discriminate between rhyme and nonrhyming stimuli and laterality was examined in several ways and for
different sub-groups of the sample. The between group difference for ability was a function of reduced dextral bias; the ability of those at the right half of the distribution always being higher than those at the left. Comparisons of subjects at both left and right extremes of the laterality continuum revealed no change in trend - sinistrals, as was originally predicted were poorer at detecting the 'odd one out' while those excessively shifted to the right of between hand differences were not. The subjects at the peak of the laterality distribution were consistently superior for ability than those at either side.

EXPERIMENT 2. WORD ORDER TEST; HOMOPHONE DISCRIMINATION & PEG MOVING ANALOGUE 'LINES'

5.4 Subjects
167 School children (79 boys and 88 girls, age range: 116-140 months, mean 127 months, sd 7.1) from one Warwickshire state school were seen in their class groups. Of these, three cases were lost from analysis due to the first language at home not being English. A further four children were excluded due to incomplete data. The analysis to be reported concerns the remaining 160 children. Order of testing was held constant throughout and in the order described.

5.2.5 Word order test - Procedure
The first exploratory experimental task devised specifically for this research project was 18 auditorily presented trials of single, monosyllable word sets; each trial was followed by a request to the
children for the written numeric order in which the words were heard above the same words presented in a different order on a pre-printed sheet. Each child was provided with a pre-printed list of eighteen sets of four mono-syllable words, half of which had sequences with first, medial or final sounds in common, and the other half being dissimilar for sound (Appendix 10). Task presentation was by a cassette recording by a male voice in a neutral prosody through loudspeakers at the front of the class.

The examiner wrote on the blackboard the words:

PINK  BLUE  YELLOW  GREEN

Then the following instructions were given:

"You should each have a list of sets of four words. Do not write anything for the moment, but listen to this example. The task is to listen to four words which will be spoken over this loudspeaker and then write down 1, 2, 3 and 4 to show the order the words were said. For example, on the blackboard are the words PINK, BLUE, YELLOW and GREEN.

The words will be said on the tape in a different order from the way they are written on the blackboard. So if the tape said BLUE, YELLOW, PINK, GREEN you would put 1-4 on the little lines above each word to show the order they were spoken in."
Does everyone understand? Now listen to the tape, and then try to write down the order. Make a guess if you are not sure, but do the best you can."

5.2.6 Homophone discrimination - Procedure

A more complex task which makes demands on auditory competence, semantics and visual coding is the second exploratory task used in this experiment. Twenty-four homophone pairs were provided on a pre-printed sheet for each child (see Appendix 9). Groups were told that one of two words on their list would be used in sentences to be read out to them by one of the examiners. Their job was to circle around the word in each pair which was the right spelling for the meaning used in the sentence. Instructions were as follows:

"Each of you should have a list of pairs of words. The words in each pair have the same sound, but different meaning and different spelling. I am going to say a sentence for each pair which uses one of the meanings. I would like you to put a circle round the word which gives the correct spelling for that meaning.

Let's try the first pair as practice.

Both of these words say 'ROOT'. A root could be part of a plant, or a route could be the way you travel on a journey. Now I will say the sentence:
'Our ROUTE was marked on the map'. That shows we mean the route which is a journey. Which one should that be? Put a circle around r-o-u-t-e.

Does everyone understand what is to be done. If you are not sure, make a guess.

5.5 Pegmoving analogue 'Lines' - Procedure

This task was an experimental attempt at providing a group test of actual hand skill that could be used as an alternative to the individual assessment demanded of the peg moving board. Only a brief summary of the task will be given here, but full procedural details are provided in the Method Chapter, page 77. Each child was provided with a pencil and a pre-printed booklet (Appendix 11). Children were scored for the number of target boxes they hit in a given time on three trials using first one hand and then the other.

RESULTS

Experiment 2: Auditory perception and immediate single word recall

The difference score for the analogue of the peg moving task, lines (R-LL) was recoded into approximate 20/30/30/20 percentages compatible with standardised between hand recoded scores (R-L) in the individual assessment of hand skill on the peg moving task, reported earlier, in this chapter for rhyme. The results of experiment 2 corroborate the general finding in the literature of the 'phonemic confusability
effect'. All children, when asked for immediate recall of both phonologically similar (those words with spoken rather than acoustic similarities) and dissimilar sequences demonstrated inferior performance on the similar sets. A MANOVA repeated measures analysis of confusable and nonconfusable scores by laterality group (4) gave a massive confusability effect (F value of 89.06, df:1,158, p≤.000), significant differences for R-L hand skill (F=2.92, df:3,156, p=.036) and no significant interactions between laterality and confusability (F=0.20, df:3,156, ns). Figure 5.1 shows that children at the left extreme of the R-L continuum were poorer at this task than children at the centre and right.

A second repeated measures MANOVA making the same comparisons as before but including sex as a variable, showed both sex and laterality to be highly significant between subject effects (F values were, for sex: 8.87, df:1,158, p=.0003 and for laterality group: 4.49, df:3,158, p=.005). There were no interactions, indicating that the influence they exerted on ability was independent of each other rather than additive (F=1.47, df:3,156, ns). Figure 5.2 presents the data graphically for sexes separately for confusable and nonconfusable sets of stimuli. Clearly, the mean number of errors is greatest for both sexes and both classes of stimuli at the sinistral extreme; the boys being the least accurate on both sets than the girls. At the dextral end of the distribution males again have the highest mean error score.
FIGURE 5.1
"CONFUSABILITY EFFECT" - WORD ORDER ERROR SCORES FOR CONFUSABLE AND NONCONFUSABLE WORD SETS WHEN CLASSIFIED BY R-LL GROUP SEXES COMBINED (N=159)

MEAN WORD ORDER ERROR SCORES

R-LL GROUP

<39  40-44  45-49  50-63

CONFUSABLE SETS

NONCONFUSABLE SETS
for confusable items while strongly dextrals females have the lowest mean error score. The trend at the dextral extreme for nonconfusable items is as would be predicted, a recovery in accuracy for both sexes; females at the right extreme having the smallest mean error score for their sex and between the sexes; the trend of better accuracy at the dextral extreme is also indicated in the performance of the males for nonconfusable stimuli. The finding of a strong sex difference, particularly at the sinistral extreme however, is contrary to what would be expected theoretically on the RS Theory, but confirms a similar finding reported for reading in Chapter 4.

Table 5.5 shows the mean number of word order errors for each laterality group. The four groups differed significantly from each other (F=3.0345, df:3,156, p=.0310) and for linear trend (F=6.4289, df:1,156, p=.0122) such that the sinistral children were worse than the mild, moderate and strong dextrals. Actual mean group errors were 4.1, 2.7, 2.3 and 2.4. This result supports the results of experiment 1 this chapter, where children lacking any dextral bias showed significantly poorer ability than all dextrals in a task of rhyme discrimination. The point being made is that not only is the recall of children at the left side of the laterality distribution disrupted by sound similarities as it was for all children, but that they remained disadvantaged even when the to-be-remembered information was phonologically dissimilar. A between group comparison between those at each extreme of the R-LL distribution was highly significant on a test of t (t=-2.482, df:155, p=.014). Tukey between group test of HSD
TABLE: 5.5  Word order errors in R-LL hand skill groups.

<table>
<thead>
<tr>
<th>R-LL GROUP</th>
<th>n</th>
<th>No. of Errors</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
<td>4.1</td>
<td>4.5</td>
<td>.8</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>2.7</td>
<td>2.1</td>
<td>.3</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>2.3</td>
<td>2.3</td>
<td>.3</td>
</tr>
<tr>
<td>4</td>
<td>33</td>
<td>2.4</td>
<td>2.4</td>
<td>.4</td>
</tr>
</tbody>
</table>

BETWEEN GROUPS:  \( F = 3.0345 \)  df: 3,155,  \( p = .0310 \)
LINEAR TERM:  \( F = 6.4289 \)  df: 1,155,  \( p = .0122 \)

PLANNED PAIRED COMPARISON BETWEEN R-LL GROUPS 1 AND 4

\[ t = -2.482 \]  df:155  \( p = .014 \)
showed that laterality group 1 were significantly different from group 3.

A two-way ANOVA for groups (4) by sex (2) was significant (F=3.882, df:4,133, p=.005), with main effects for both sex and group (Table 5.6, sex: F=6.766, df:1,133, p=.01; group: F=3.678, df:3,133, p=.014). No significant interactions were observed. The prediction that non-dextrals would have higher mean error scores than mild, moderate or strong right handers was confirmed for both sexes.

A Pearson correlation between word order errors and R-LL group, was non-significant (r=-.1230, n=159, p=.061).

The negative value of r indicating the inverse relationship between word span and laterality in that as dextrality increases so does recall span. A stepwise multiple regression analysis including sex, chronological age (CA) and laterality as possible predictors of word order performance showed only sex to be significant (Multiple R = 0.45413, F=17.53725, p<.000; CA t=-.652, ns; R-LL t=-1.452, ns). An additional fixed order regression analysis including sex, CA, English score and R-LL showed both English and sex to be significant (Multiple R=.42747, F=30.40859, p<.000; Multiple R=.45413, F=17.53725, p<.000). Both CA and R-LL were nonsignificant (CA t=-.652, ns; R-LL t=-1.452, ns).

Homophone discrimination

This task was designed to ask whether children at the right extreme of 165
<table>
<thead>
<tr>
<th>R-LL GROUP</th>
<th>Males</th>
<th>n</th>
<th>Females</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.0</td>
<td>9</td>
<td>3.5</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>3.3</td>
<td>18</td>
<td>2.0</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>2.6</td>
<td>22</td>
<td>2.3</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
<td>16</td>
<td>1.2</td>
<td>13</td>
</tr>
</tbody>
</table>

**TABLE 5.6**
Word order errors, sexes separately (males n=65, females n=73) when classified in R-LL hand skill groups.

**MAIN EFFECTS**
- \( F = 3.882 \) df: 4,133, \( p = .005 \)
- \( F = 3.678 \) df: 3,133, \( p = .014 \)
- \( F = 6.766 \) df: 1,133, \( p = .010 \)
between hand differences (the strongly right-handed children) would make more homophone errors than those elsewhere in the distribution.

There were no significant group differences and no effects for trend, ANOVA for homophone errors by laterality group (F=.3351, df:3,155, ns) Table 5.7. Those with the highest mean errors were again as for the previous task, more likely to be in laterality group 1 (means: 2.1, 1.8, 1.9 and 1.6) however, the distribution of the scores into the four R-L groups was remarkably even. Planned paired t test comparisons between groups at each extreme of the laterality continuum failed to reach significance (t=.943, df:156, ns). Table 5.8 shows means and n's for homophone errors classified by laterality and sex. Males were again generally slightly poorer than females but the strength of the effect was relatively weak. A two-way ANOVA groups (4) by sex (2) showed no main effects for laterality group (F=0.222, df:3,135, ns), and no significant effects for sex (F=3.225, df:1,135, p=.075). A Tukey test of HSD was nonsignificant.

No significant association between homophone errors and laterality was observed on a Pearson correlation (r=-.0096, n=160, ns). A fixed order multiple regression including sex, CA, English score and R-LL showed English score to be the most important predictor accounting for 53% of the total variance (Multiple R = .52977, F = 53.45140, p<.000) with CA and sex increasing the R squared value by a further 5% (Multiple R = .55255, p<.000, Multiple R = .57169), R-LL being non-predictive of performance (t=.982, ns).
TABLE: 5.7 Homophone errors in R-LL hand skill groups.

<table>
<thead>
<tr>
<th>R-LL GROUP</th>
<th>n</th>
<th>( \bar{x} ) No. of Errors</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32</td>
<td>2.1</td>
<td>1.6</td>
<td>.3</td>
</tr>
<tr>
<td>2</td>
<td>42</td>
<td>1.8</td>
<td>1.7</td>
<td>.3</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>1.9</td>
<td>2.1</td>
<td>.3</td>
</tr>
<tr>
<td>4</td>
<td>33</td>
<td>1.6</td>
<td>2.3</td>
<td>.4</td>
</tr>
</tbody>
</table>

BETWEEN GROUPS  \( F = .3351 \) df: 3,155, ns.
LINEAR TERM  \( F = .5645 \) df: 1,155, ns.

PLANNED PAIRED COMPARISONS BETWEEN R-LL GROUPS 1 AND 4

\( t = -.943 \) df: 155, ns.
TABLE 58
Homophone errors, sexes separately (males n=65, females n=73) when classified in R-LL hand skill groups.

<table>
<thead>
<tr>
<th>R-LL GROUP</th>
<th>Males</th>
<th>Females</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.6</td>
<td>1.8</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>1.5</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>2.1</td>
<td>1.9</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>2.2</td>
<td>1.2</td>
<td>13</td>
</tr>
</tbody>
</table>

MAIN EFFECTS

<table>
<thead>
<tr>
<th>Effect</th>
<th>F</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-LL GROUP</td>
<td>.887</td>
<td>4,133</td>
<td>ns</td>
</tr>
<tr>
<td>SEX</td>
<td>.222</td>
<td>3,133</td>
<td>ns</td>
</tr>
<tr>
<td>SEX</td>
<td>3.225</td>
<td>1,133</td>
<td>.075</td>
</tr>
</tbody>
</table>
Despite the consistent failure to find any significant differences for laterality for the homophone task, it is important to note that the same children, poor for phonology at the left extreme of the laterality continuum are not poor for homophones at the left, i.e. a dissociation even if not a double one as was originally predicted.

5.6 DISCUSSION

The principal finding of this study was that children poor at rhyme discrimination and short term memory for confusable (rhyming) and nonconfusable sets of words were more frequently at the left of the laterality distribution. This finding lends support to Annett's argument that deficits in phonological encoding are more likely in those without the added bonus of left hemisphere speech specialization, and hence right hand bias (expected to include a greater proportion of rs—genotypes). The trends in the present data are also in agreement with Brady, Shankweiler & Mann (1983); Mann, Liberman & Shankweiler (1980); Bryne & Shea (1979); Shankweiler, Liberman, Mark, Fowler & Fischer, (1979) and Snowling (1980), who found a confusability effect between good and poor readers. The results thus reflect the general finding in the literature that for immediate memory, nonconfusable items are better recalled than confusable items (Baddeley, 1986; Snowling, 1987).

It might be pertinent to note at this point that a single, unitary measure of phonology does not exist. As previously noted (page 43) language deficits associated with left- and mixed-handers or poor or
good readers are based on studies which have relied on vocabulary scores, explicit awareness of syllables or single phonemes (spoken or motor responses by tapping out the number perceived), letter-to-sound matching, nonword reading/spelling and stuttering to represent 'phonological dysfunction'.

The present study's finding of a quadratic relationship between ability and laterality (Table 5.4) and the significant effect for reading group do replicate the general finding reported in Annett & Kilshaw (1984) and adds weight to Annett's hypothesis of a human balanced polymorphism with heterozygote advantage for ability.

The description of phonology, the focus of interest for the first part of the present investigation's hypothesis was sub-divided into two components: Rhyme detection and short term memory. It was found that 'type' of phonology considerably affected the strength and form of the relationship observed between laterality and phonology. Rhyming ability for instance, was more accurate for mild and moderate dextrals than those at left and right extremes of the laterality continuum (the quadratic relationship) - Tables 5.4, 5.5 (the exception to this general effect being the mildly dextral males). For short term memory (the word order test) the relationship is significantly linear, with ability increasing from left to right across the continuum of R-L differences. The poorest group being the children at the sinistral extreme and the best at the dextral tail, with a significant effect for sex.
Inspection of Figure 5.1 shows clearly that all children do better on nonconfusable than confusable sets of words, but that sinistrals are worse at both relative to the rest of the distribution. These finding corroborate experimentally the findings of Liberman (1970; 1974; 1980); Bradley & Bryant (1978) in showing individual differences in explicit awareness of phonology. They are also unique in that they are the first to show a relationship between the confusability effect and handedness in a normal, unselected population sample.

However, closer inspection of the group means and s.d.s for the word order task, sexes separately (Table 5.6), suggests that a degree of caution might be appropriate. While inter-group variability for performance was relatively even for mild, moderate and strong dextrals the accuracy of the sinistral group varied considerably. Thus the observed effect may in reality be reflecting a few extreme scores on the part of the males in this laterality group, or that these children were poor readers (a suggestion which would be difficult to reconcile, in terms of direction of cause and effect, with Annett's theoretical views), or it could simply be a case of sampling error. Do the findings indicate that reading experience increases awareness of phonology, or vice versa? A closer look at Appendix 10 shows that a failure on the part of the experimenter to counter balance word sets for the number of sound elements that were similar has introduced the possibility of an order effect. Further experiments would need to substantiate these results before any firm conclusions can be drawn.
The pathological left hemisphere hypothesis advocated by Geschwind & Galaburda (1985) is strongly questioned by the present data, for to support such arguments we would have expected the effects to be limited only to those with poor right hand skill (left hemisphere weakness), and this was not the case. Right hand skill has not been shown to be the important variable in differences in phonological awareness. In agreement with Annett (1973) and Dennis & Whitaker (1977) the present findings suggest that the effect of left hemisphere inefficiency is specifically on language and not on intelligence per se.

That the type of phonology could influence the nature of the relationship between ability and laterality should not, however, detract from the important finding that children at the left extreme of the continuum for both measures were always the least able. In agreement with the previous experiment, there were no significant interactions between laterality, sex of child or phonology. There were no significant differences to be found between the sexes regarding accuracy of rhyme detection. Therefore there is little support for the pathology hypothesis of Geschwind & Galaburda, that left- and mixed-handed males are worse, because of left hemisphere damage, than females for specific language problems in a normal, unselected population of school children. While females gave marginally better performance for the rhyme task than males, this difference fell considerably short of significance.

The second part of the hypothesis is however, more difficult to
substantiate, and could not be tested legitimately as considerable inter-group consistency in mean homophone scores were found. From Tables 5.7 and 5.8 it can be seen however, that the obtained mean errors were all different from each other, but in the wrong direction from that predicted. Annett's hypothesis was not confirmed at any acceptable level of significance. Children excessively biased to the left hemisphere/right hand were not poorer on the homophone task (presumed to depend on good visuo-spatial or nonverbal processing) than children reduced in dextral bias.

There are several possible explanations for this null finding. The first may in some way be linked to differences in processing strategies employed. The choice of task was founded on the assumption that it could not be solved successfully by phonological processing, but relies on memory for spelling (likely to be a visual, orthographic representation). Therefore strong dextrals, because of their predicted overdependence on left hemisphere language processing, would make more errors. However, as Barron & Baron (1977) have pointed out it is possible that children could learn by paired association between a printed form and its meaning and completely by-pass any processing demands on sub-lexical phonology. Thus the phonological processes occurring, at either input or output stage, may be argued to be quite different. It is suggested that a lack of control over individual differences in preferred processing strategy was a major factor in failure to observe a laterality effect.
It is just as feasible to argue that this task was heavily dependent on short term memory rehearsal and storage of the presented sentences (left hemisphere function?) and it is the accuracy with which this information is encoded (remembered) when the second phase of the task is reached rather than the target pairs of words which is vital to accuracy; if this were so then again the nondextrals would have been disadvantaged. Interestingly, Ellis (1986) considers there to be good evidence that a direct connection between meanings and graphemic information of known words exists alongside a separate speech lexicon which when activated makes available the individual phonemes of the heard word. Is it therefore essentially a left hemisphere directed task? Clearly, presentation of verbal or nonverbal stimuli does not guarantee that all subjects will employ a unitary processing strategy. This is a possibility which should not be ignored.

A second possible reason for the lack of effect lies in the presumed role of the right hemisphere. Consideration of the studies of brain damaged patients has provided strong support for regarding the left hemisphere, for most of us, as mediating language and the right hemisphere for perceptual, visuo-spatial operations. However, recent evidence by Farah (1988) suggests that the left-hemisphere may have a nonverbal role in the mediation of important visuo-spatial functions. This finding demonstrates that there is not necessarily a mirror relationship between left hemisphere language representation and right hemisphere spatial ability - they may simply not be associated. Obviously, this suggestion holds important implications for the RS Theory.
What is considered to be important however, is that despite the lack of a significant laterality effect for homophones, the results between the rhyme and word order task and homophone discrimination demonstrate a dissociation (good at one but not the other) but not a double dissociation (good at one and poor at the other and vice versa). Therefore, the tasks may depend on separate but interactive structures similar to that discussed by Baddeley (1986) (the articulatory loop and visual sketch pad).
6.1 Introduction

From the analysis in Chapter 4 recorded in Table 4.1b, it was clear that the hypothesis advanced, that specific reading retardates would be in excess at the left and backward readers at the right extreme of the laterality continuum, was disconfirmed. The results did identify two sub-groups of poor readers. However, contrary to theoretical expectations an excess of children whose reading progress was "only one aspect of their general retardation" (Tizard Committee, 1972), referred to as 'backward readers' in the Rutter et al (1970) population survey, were found to be reduced in dextral bias (at the left extreme of R-L differences). Conversely, "children whose reading abilities are significantly below the standards which their general abilities in other spheres would lead one to expect" (Tizard Committee, 1972), Rutter et al's 'specific reading retardates' were more likely to be strongly biased in favour of their right hand/left hemisphere. In the preceding study, the hypothesis that visual memory for words would be poorer in those at the dextral than sinistral extreme of the distribution of between hand differences was also not supported.

This final study should be regarded as an initial exploratory exercise designed to serve as a 'signpost' to future research. The general question which was addressed was whether there were differences in
spelling ability in children classified for laterality and whether
dysphonetic/phonological or dyseidetic/surface sub-types of spellers
(Boder, 1973; Mattis, French & Rapin, 1975) can be identified.

More specifically it aims to test the prediction of the RS Theory that
children at the left extreme of the laterality continuum will more
often (be at greater risk) of making errors which depend on
sound/speech analysis (i.e. plausible pronunciations, syllables, and
vowels - phonological problems). As noted in the Chapter 1 (page 44)
the most conspicuous characteristic distinguishing the
dysphonetic/phonological from the dyseidetic/surface dyslexic is the
former's poor nonword relative to word reading and the latter's tendency
to regularization (reading regular better than irregular words). It is
to this that we now turn.

6.2 Method and procedures:

6.2.1 Subjects

68 Schoolchildren, unselected for either ability or laterality, (31
males and 37 females) participated in this study. The average age of
the males was 10 years 2 months (122 months) range 116-127 months and
the females 9 years 8 months (116 months) range 116-128 months. All
pupils attended one state comprehensive school in Warwickshire and were
from a single year group.

Children were seen in pairs in their register order by two examiners
working in parallel in one room. Each child was required to take part
in a series of tasks. While one child was being assessed for reading,
the other, wearing headphones and at the opposite side of the room, carried out the spelling test. The children were so positioned that they were back to back so that neither could see what the other was doing. The child taking part in the reading assessment never followed directly onto the spelling condition but was given other, unrelated intermediate tasks, i.e. Ravens Matrices or clock drawing, and therefore was not able to familiarise or be directly primed as a consequence of task order.

The tasks used in this study are peg moving, nonverbal intelligence reading and spelling.

6.2.2 Peg Moving
Children were individually tested on Annett's (1970) peg moving task. As described fully elsewhere in this thesis (Method chapter, page 70) the main demand of the task being to move wooden pegs one at a time from a row of holes furthest away from the body to another parallel row nearest the body in the fastest time possible. R-L groups were as for reading in Chapter 4 (lowest through 43, 44 through 53, 54 through 61 and 62 through 94) reflecting absent, mild, moderate and strong bias towards dextrality.

6.2.3 Spelling
Using a Bell Howell tape recorder a cassette tape was compiled using the first ten words of Boder & Jarrico's (1982) Seventh Grade (List 7) spellings as published, followed by the second half of the list subsequent to the alteration of the initial phoneme (see Appendix 6
for actual list presented). The recording generated a continuous stream of 20 stimuli, half words and half nonwords, spoken by a male voice in a neutral prosody heard through headphones with stereo from a mono adapter so that the stimuli were played to both ears and heard in the middle of the head.

Regular and irregular spellings were counterbalanced across the whole list. Instructions given by the examiner to each child were as follows:

"I would like you to listen to some words on this tape. After each word, write down what you hear. It may be a word you know, or a word you do not know. It could even be a pretend word. Try your best to write it down, and make a guess at the spelling. Write the words, one on each line, in a list on this paper. The tape recording will begin by saying, 'write down these words, ready'. Do you understand?"

Presentation of the stimuli was followed immediately by a five second delay in which the child wrote down their spelling on the lined paper provided. After hearing the instructions, the examiner asked if there were any questions, any asked were answered. The children were then instructed to put the headphones on and when satisfied that they were placed correctly, the examiner began the tape.

A pilot study (in two other state schools) had shown that spelling lists prior to the Seventh Grade were not appropriate for the purpose of the current investigation. Level of difficulty was the
criterion for choosing the presented list. In this way subjects were deliberately forced into making errors when hearing an unfamiliar letter string. Other empirical work reported in the literature (Boder, 1973; Frith, 1980) had shown this technique to be a useful means for the identification of children over reliant or neglectful of a sound based strategy for spelling words and nonwords.

The accepted definition of a plausible pronunciation adopted in the present study was that used by Frith (1980) i.e. when the letters written by the child were reconstructed, they could produce an acceptable pronunciation of the word. The definition is not meant to convey any measure involving acoustic or articulatory features of the speech sound. If the written response (incorrectly spelt) did not comply with this definition then the spelling was not scored as a plausible pronunciation. In addition to level of difficulty the Boder & Jarrico lists were also chosen to control for regular and irregular spelling patterns as these are alternated throughout all levels of spelling lists in this test.

6.3 RESULTS

Method of Analysis:
Word and nonword lists were classified into four mutually exclusive categories: correct number of syllables, correct vowels and consonants and when reconstructed on the basis of letter sounds they made a plausible pronunciation. Only those attempts which were correct for each of the categories were used in the analysis. Spellings that
suggested miss-perceptions of presented stimuli were classed as errors. These were generally cases where the spellings produced were real word substitutions for nonwords presented or derivatives of a word, for example *NEVERTHELESS* for the nonword *DEVERTHELESS* or *FREQUENT* for *FREQUENCE* which were obviously closely related either semantically or phonemically. Instances where the child failed to write down anything at all were also included in the overall error total. Other errors scored but not reported in this present report, because of their infrequency, were semantic substitutions, extra letters, position of error and present but incorrect vowels.

6.3.1 How are types of written spelling distributed in a normal population of schoolchildren?
Table 6.1 presents a frequency distribution for syllables, vowels, consonants and plausible pronunciations, sexes combined, for correct words (regular + irregular) and nonwords separately. The only difference of any note is that children are better at including the correct number of letters in nonwords than they are for words, otherwise they are generally better at spelling words than they are at nonwords (see Figure 6.1 for a histogram representation of the same data analysis). The differences were not statistically significant.

The next analysis was for spelling accuracy when classified for sex and laterality. The number correct for regular and irregular words were combined to give a single value for each spelling measure, for example:

\[
\text{number correct for regular words + number correct irregular words} = \]

182
vowels. Tables 6.2 and 6.3 present the distribution of correct regular and irregular spellings x sex x laterality group. There were no significant between group or sex differences, or significant interactions in either instance.

Each spelling score was subsequently entered into stepwise regressions (Sex, C.A, Reading Age, I.Q., R-L, LPEGST, RPEGST) by each of the spelling measures separately. The multiple regression results presented in Table 6.4 show clearly that Reading age made the most significant contribution to the variance of all spelling measures (syllables: $R^2_{\text{Change}}$ .300, $p < .0000$; vowels: $R^2_{\text{Change}}$ .469, $p < .0000$; consonants: $R^2_{\text{Change}}$ .445, $p < .0000$; plausible pronunciations: $R^2_{\text{Change}}$ .458, $p < .0000$). As perhaps would be expected children who are good readers are generally also good spellers.

Once reading had been accounted for C.A. made a further significant contribution, in $R^2_{\text{Change}}$, to vowels ($R^2_{\text{Change}}$ .080, $p = .02$) and plausible pronunciations only ($R^2_{\text{Change}}$ .089, $p = .01$). For syllables, consonants and plausible pronunciations, between hand skill and skill of each hand were significant contributors to $R^2_{\text{Change}}$ (syllables RPEGST $R^2_{\text{Change}}$ .039, $p = .05$; consonants R-L, $R^2_{\text{Change}}$ .066, $p = .004$; RPEGST $R^2_{\text{Change}}$ .053, $p = .006$; plausible pronunciations LPEGST $R^2_{\text{Change}}$ .039, $p = .02$). Sex made no significant contribution to the variance on any measure of spelling (syllables $R^2_{\text{Change}}$ .003, ns; vowels $R^2_{\text{Change}}$ .015, ns; consonants $R^2_{\text{Change}}$ .005, ns; plausible pronunciations $R^2_{\text{Change}}$ .000, ns). In view of the lack of any
TABLE 6.1  The distribution of handwritten spelling error type for words and nonwords in a normal population sample of school children, sexes combined (N=68).

<table>
<thead>
<tr>
<th></th>
<th>Syllables</th>
<th>Vowels</th>
<th>Consonants</th>
<th>Plausible Pronunciations</th>
</tr>
</thead>
<tbody>
<tr>
<td>WORDS</td>
<td>8.0</td>
<td>5.2</td>
<td>3.5</td>
<td>4.2</td>
</tr>
<tr>
<td>SD</td>
<td>2.0</td>
<td>2.3</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>NONWORDS</td>
<td>7.2</td>
<td>4.2</td>
<td>5.5</td>
<td>3.7</td>
</tr>
<tr>
<td>SD</td>
<td>2.4</td>
<td>1.7</td>
<td>2.3</td>
<td>1.8</td>
</tr>
<tr>
<td>R-L GROUP</td>
<td>n</td>
<td>Syllables SD</td>
<td>Vowels SD</td>
<td>Consonants SD</td>
</tr>
<tr>
<td>-----------</td>
<td>---</td>
<td>-------------</td>
<td>-----------</td>
<td>--------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[ \bar{X} ]</td>
<td>[ \bar{X} ]</td>
<td>[ \bar{X} ]</td>
</tr>
<tr>
<td>Males</td>
<td>1</td>
<td>7</td>
<td>1.787 4.4</td>
<td>0.976 2.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7</td>
<td>1.254 4.3</td>
<td>1.604 2.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8</td>
<td>1.832 3.7</td>
<td>0.707 1.7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9</td>
<td>1.000 4.3</td>
<td>1.302 2.2</td>
</tr>
<tr>
<td>Females</td>
<td>1</td>
<td>9</td>
<td>2.000 4.0</td>
<td>1.803 2.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>1.000 4.0</td>
<td>1.787 2.2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9</td>
<td>1.833 4.2</td>
<td>0.866 1.7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>10</td>
<td>1.509 3.5</td>
<td>1.059 1.3</td>
</tr>
</tbody>
</table>
TABLE 6.3  Classification of spelling type by laterality group, by sex - mean number correct, irregular words.

<table>
<thead>
<tr>
<th>R-L GROUP</th>
<th>n</th>
<th>Syllables</th>
<th>Vowels</th>
<th>Consonants</th>
<th>Plausible Pronunciations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>x</td>
<td>SD</td>
<td>x</td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>1.254</td>
<td>3.7</td>
<td>1.380</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>.690</td>
<td>3.8</td>
<td>1.345</td>
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</tr>
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<td>3</td>
<td>8</td>
<td>.886</td>
<td>4.2</td>
<td>1.506</td>
<td>3.4</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>1.000</td>
<td>4.0</td>
<td>1.014</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>1.581</td>
<td>3.7</td>
<td>1.641</td>
<td>3.2</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>.441</td>
<td>4.2</td>
<td>1.414</td>
<td>3.7</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>.833</td>
<td>4.2</td>
<td>1.225</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>1.197</td>
<td>3.9</td>
<td>1.350</td>
<td>2.6</td>
</tr>
</tbody>
</table>
significant sex differences in all remaining analyses the sexes were combined. Thus the results illustrate the importance of both reading ability and laterality (both hands and hence both hemispheres) for spelling accuracy.

In order to investigate whether children at the left side of the laterality continuum (more likely rs-- genotypes) made more spelling errors which depended on phonology a total score which combined the number correct for words, regular and irregular together with number correct for nonwords was computed to give a single value for each child on each spelling variable (for example Vowels = Vowels correct for regular words + vowels correct for irregular words + vowels correct for nonwords). This method of computation was used for each spelling variable.

The principal findings of the MANOVA analysis (vowels, syllables, consonants, plausible pronunciations X R-L group (4) are presented graphically in Figure 6.2. Inspection of Figure 6.2 shows that only children at the left extreme (R-L group 1) were found to be worse at detecting the correct number of syllables compared to mild, moderate and strong dextrals. Against prediction they were better than moderate and strongly dextral children (in R-L groups 3 and 4) for both vowels and plausible pronunciations and slightly better than moderate dextrals for consonants. None of the differences were statistically significant (Between subjects effects R-L Group F=.41,df:3,64,ns; within subjects effects R-L Group x Spelling scores F=1.03,df:3,64,ns). It is relevant
FIGURE 6.2
SPELLINGS, BY TYPE, CORRECT WHEN CLASSIFIED BY
R-L GROUP, SEXES COMBINED (N=68)

SYLLABLES

VOWELS

CONSONANTS

PLAUSIBLE PRONUNCIATIONS

MEAN NUMBER CORRECT

MEAN NUMBER CORRECT

MEAN NUMBER CORRECT

MEAN NUMBER CORRECT

R-L GROUP

R-L GROUP

R-L GROUP

R-L GROUP
### TABLE: 6.4  Stepwise regression, words (regular+irregular)
Syllables, Vowels, Consonants and Plausible Pronunciations (N=68)

<table>
<thead>
<tr>
<th>Dependent variable: Syllables</th>
<th>Multiple R</th>
<th>$R^2$ Change</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sex</td>
<td>.059</td>
<td>.003</td>
<td>ns</td>
</tr>
<tr>
<td>2. Age (C.A.)</td>
<td>.199</td>
<td>.036</td>
<td>ns</td>
</tr>
<tr>
<td>3. Reading Age (R.A.)</td>
<td>.583</td>
<td>.300</td>
<td>.000</td>
</tr>
<tr>
<td>4. Ravens Matrices Percentile (I.Q.)</td>
<td>.594</td>
<td>.013</td>
<td>ns</td>
</tr>
<tr>
<td>5. Between hand skill (R-L)</td>
<td>.607</td>
<td>.015</td>
<td>ns</td>
</tr>
<tr>
<td>6. Left hand skill (LPEGST)</td>
<td>.639</td>
<td>.039</td>
<td>.0496</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dependent variable: Vowels</th>
<th>Multiple R</th>
<th>$R^2$ Change</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sex</td>
<td>.125</td>
<td>.015</td>
<td>ns</td>
</tr>
<tr>
<td>2. C.A.</td>
<td>.310</td>
<td>.080</td>
<td>.019</td>
</tr>
<tr>
<td>3. R.A.</td>
<td>.752</td>
<td>.469</td>
<td>.000</td>
</tr>
<tr>
<td>4. I.Q.</td>
<td>.752</td>
<td>.000</td>
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at this point to draw the readers attention to the finding that, although not significantly so, in every instance those children mildly biased in favour of their right hands (R-L group 2) always achieved the highest scores on all spelling measures and were therefore consistently the most able spellers.

A subsidiary question was whether poor spellers who were also poor readers made different types of spelling errors than good readers who are also poor spellers and whether they differed for laterality. Poor readers were defined as those scoring less than average (40) for predicted reading when age and intelligence is controlled (stresids) and good readers as those achieving beyond this score on the same criteria. Spelling score was as reported in the previous section - combining the number correct for regular, irregular and nonwords to make a total score for each variable.

As previously stated, reading ability holds important implications for spelling accuracy. When the sample were divided into poor and good readers, the spelling accuracies of these two reading groups were significantly different. The results of two-way ANOVA's, spelling measure x R-L group (4) x reading group (2) are presented graphically in Figures 6.3 and 6.4. In every case the main effect was of reading group, vowels (F=23.333, df:1,66, p<.000), syllables (F=9.618, df:1,66, p=.003), consonants (F=24.986, df:1,66, p=.003), plausible pronunciations (F=31.639, df:1,66, p<.000). There were no significant effects for laterality or two-way interactions.
FIGURE 6.3 GOOD AND POOR READERS SPELLING ACCURACY IN R-L GROUPS

- GOOD READERS
- POOR READERS

\[ \bar{x} \text{ SYLLABLES CORRECT} \]

- \( \bar{x} \text{ CONSONANTS CORRECT} \)

R-L GROUP

<3  4-13  14-21  22+

191
Two sub-groups of poor readers and poor spellers were identified who differed for laterality: One group at the left side of the laterality distribution who were poor at elements of spelling which required good phonological skills and another group, whose laterality distribution was strongly biased towards dextrality who were poor at including the correct consonants.

Of particular interest for present purposes and in the light of the finding of a significant relationship between intelligence, sub-groups of poor readers and laterality found in Chapter 4 was whether sub-groups of poor spellers would also be found who differed for both intelligence and laterality. As Figures 6.3 and 6.4 demonstrate, it is clear that the spelling ability of strongly dextral good readers dropped quite noticeably for three out of four of the spelling measures (syllables, plausible pronunciations and vowels).

Could this be a consequence of poor intellect generally for those at the dextral extreme of the laterality continuum? MANOVA analysis revealed that the mean IQ scores for those children whose laterality distribution was strongly biased towards dextrality was considerably lower than those reduced in dextral bias (mean IQ: 50, 44, 52 and 32, R-L groups 1-4 respectively. The covariate value was highly significant (t= 3.24047, p=.002). The findings from the present study have shown that while the majority of good readers are also good spellers, there are a minority of children who are doing less well at spelling than would be expected by their reading attainment but in
FIGURE 6.4: GOOD AND POOR READERS SPELLING ACCURACY IN R-L GROUPS
accordance with their intellectual level.

By far the most important and consistently reported difference between surface and phonological dyslexics is that the former present a regularity effect (read regular words better than irregular ones) while the latter do not. As mentioned earlier, the words in the spelling lists presented to this sample were counterbalanced for regular and irregularity. The results are reported in Tables 6.2 and 6.3: Children were not significantly better at spelling regular than irregular words. MANOVA analysis for all spelling measures in Regular, Irregular Words x R-L Group (4) by sex (2) showed no significant between or within group differences for laterality. There were no significant sex differences nor interactions.

Finally a comparison of nonword versus word spelling accuracy was made (see Table 6.1, Figure 6.1, pages 184 and 185). In contrast to the previous section the most reliable predictor of phonological but not surface dyslexics is that phonologicals are poor at nonword compared to word reading, a deficit not generally found in the pure case of the surface dyslexic.

The difference between number correct for regular and irregularly spelt words (in an attempt to control for possible guessing strategies) for each child on each spelling variable was computed to provide a total score correct for words. Similarly an overall score for nonwords was arrived at by subtracting the number correct from the sum of the regular and irregular word score. These two totals, one for words and
<table>
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<tr>
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another for nonwords (based on frequency distributions) were subsequently recoded into poor, average and good ability bands (word recodes: lowest through -4.0=1, -3.0 through 2.0=2 and 3 through 13=3; nonwords: lowest through -1.0=1, 0 through 7=2 and 8 through 22=3). Chi Square analysis, word groups (3) by nonword groups (3) showed no significant differences ($X^2=5.16792, df:4, ns$). Thus for accuracy in spelling words versus nonwords there were no significant effects.

Following the procedure detailed by Temple (1984) a single case study approach was utilized in an attempt to distinguish between surface and phonological type spellers in a sample of normal children. Using this rationale and keeping both total scores and recodes as described in the previous section for word and nonwords, the ID numbers of children hypothesized as surface spellers (good at nonwords, recode group 3) but not words (recode groups 1 and 2) and phonological spellers, good at words (recode group 3), but not nonwords (recode groups 1 and 2) were selected from the main sample. The frequency analysis identified ten children as phonological type spellers and eight as surface types. The comparison of spelling errors made by individually identified surface and phonological type spellers are given in Table 6.5, page 195.

6.4 DISCUSSION

The results of this study are largely inconclusive. At best they have served to offer a first tentative answer to the general question of the distribution of different spelling elements. What evidence is available from this small study, is enough to suggest the
possibility that poor spellers at the left of the laterality continuum are more likely to make phonological spelling errors. No evidence was found for the opposite effect (orthographic errors) in poor spellers at the dextral extreme. Although these analyses produced no significant findings, the mean spellings correct for laterality groups were in the direction predicted theoretically.

Spelling accuracy was not shown to differ between regular, irregular, word or nonwords or to be significantly associated with laterality. The results showed that once reading ability had been taken into account, neither sex nor laterality were of any significant importance. However, there may be widespread individual differences in the reading age of the present sample therefore any subsequent investigation should more directly control for this factor in order to determine whether the present lack of effect for laterality or spelling type would subsequently be observed.

Differences between word and nonword stimuli seems to have been of minimal importance for spelling accuracy for the present sample. This is in direct conflict with many of the findings from clinical samples and may have been an artifact of the experimental design. However, as Temple (1987) makes clear, difficulties with nonword reading is not necessarily a general characteristic of all dyslexic readers. In support of this claim she cites the case of RB, a surface dyslexic who presents no deficits in nonword reading. The failure to show a word-nonword effect may have been an atypical response by subjects in
this study, in that there was some doubt on the part of the experimenter as to whether they were sure what was expected of them. It should be noted that these same children in an unreported study of word and nonword reading (by the present experimenter) were extremely difficult to convince that they were to pronounce nonwords and not some known real word that was phonologically or visually similar to the target letter string. Such problems would need to be more closely monitored in any subsequent research of this nature.

The results of the regression analysis recorded in Table 6.4 do indicate, however that once reading ability has been accounted for, the skill of each hand (and therefore both hemispheres) is important for spelling accuracy in three out of four of the spelling measures employed.

Table 6.5 provided partial support for the second prediction that there were children in normal population samples who resembled the characteristics expected of the clinical surface and phonological type speller - although this was not shown to be significantly related to laterality.

The present work merely suggests one possible way in which children in normal populations with similar patterns of deficits as those distinguished in the clinical tradition might be identified. There were no indications from teachers that any of the children were speech or hearing disordered in any way. The important point is that subtle
meta-linguistic skills may be what underlies spelling proficiency rather than the more obvious expressive or communicative ability.
Summary

The preceding three experiments were primarily concerned with the cause of deficit in those individuals at left and right extremes of the laterality continuum - the hypothesised double dissociation between those having too much of the rs factor (the rs- genotypes) and those having too much (the rs+ genotypes). The weight of attention was devoted to two variables: Phonological and visual encoding efficiency of written language.

In agreement with Annett (1985) it was found that the extent of bias favouring right-handedness could play a significant role in determining the accuracy of children's phonological awareness. Sinistrals, were found to be significantly less accurate than strong dextrals in their recall of sets of words regardless of whether they had sounds in common or not, and in discriminating between words that rhymed and those that did not. Exploration of this effect suggested that it may originate from an articulatory loop effect at the stage of input.

Possible order effects were found and, as such, indicate that a certain degree of caution concerning the results should be exercised. However, the findings of the present experimentation add to the recent literature which suggest that auditory and visual processing effects in poor readers may well be even more complex and subtle than previous investigations had realised.

A return was also made to the findings in the first study, specifically
the effect of nonverbal reasoning on visual and verbal processing. The effect was examined in terms of Annett's proposal that the disadvantages associated with absence of the right shift factor, the rs+ gene, and hence bias to the left hemisphere/right hand would be specifically to speech encoding and not to visuo-spatial reasoning. Evidence was found in support of the deficits to language processing in those at the left but not the right of the distribution of between hand differences.

The use of a small sample size to study spelling accuracy when classified for laterality provided a clear note of warning concerning the impracticability of expecting laterality effects to emerge from relatively small sample sizes.

Thus the final stages of the present thesis fulfilled the aims described in the Chapter 1 (page 64): To explore further the current distinctions in the reading literature between dysphonetic and dyseidetic dyslexia, and to investigate what possible links there might be between these sub-types and lateral asymmetry.

In the final discussion, it is necessary to make salient the many points which have emerged throughout this present investigation. Special attention will be made of their appropriateness to the original aim of this thesis: to evaluate and test the RS Theory's hypothesis of a human balanced polymorphism with heterozygote advantage for ability.
CHAPTER SEVEN

General Discussion

The studies reported in the preceding chapters were, as fully described earlier (page 64) designed to empirically evaluate Annett's hypothesis of a human balanced polymorphism with heterozygote advantage for ability: that among individuals with certain special psychological abilities and disabilities left and right extremes of the laterality distribution will be over-represented in comparison with the majority who are moderately biased to their left hemisphere/right hand. The main experimental findings are considered within the context of current research on speech, reading and related skills. This discussion will deal with each study's experimental results together with their practical and theoretical implications.

The subject of the first study was the population distribution of nonverbal reasoning ability and its association with asymmetries of hand and brain. The primary aim of this investigation was to empirically test Annett's proposition that the source of observed disadvantages for nonverbal reasoning ability in some individuals resides in the action of a single gene, the rs+. Although conferring advantages for language skills by facilitating the development of speech in the left hemisphere when carried in a single copy, rs+-, when two copies of the gene are present, as is the case of the homozygotes rs++, the facilitation goes too far and results in a few individuals who are significantly handicapped for those skills.
traditionally associated with right hemisphere visuo-spatial processing.

These first results suggested that strong dextrality depended on left hand weakness not right hand superiority in skill, and was significantly associated with poor nonverbal ability. Both sexes at the dextral extreme of between hand differences (R-L group 4) were significantly worse at nonverbal reasoning than children less biased towards right-handedness. Annett’s views together with others who have maintained that left-handers have an advantage over right-handers for those abilities thought dependent on right hemisphere function have been directly supported by the experimental findings (Annett & Kilshaw, 1982; Geshwind & Galaburda, 1985; Benbow, 1986).

In general terms the experimental findings are not in conflict with the predictions of any of the theoretical views presented in Chapter 1. However, as was noted elsewhere (page 5) the "Geschwind Hypothesis" considers that the mechanism underlying structural differences between the two sides of the brain leading to variable enhancement of the right hemisphere for the majority, is determined by selective slowing down in growth of certain 'zones' in the left hemisphere. Expanding this premise one step further it is to be expected that the right-hand of nonright-handers would be significantly slower than either their left-hands or the right hands of intellectually less able children. The findings of this first
study clearly showed neither of these predictions to be true and therefore raises doubts about pathology explanations of individual differences for either handedness or nonverbal ability.

The results do, however, lend support to Annett's claim that the benefits gained by left hemisphere speech development are only met by damping down in some way the efficiency of the right hemisphere, and that when the left hemisphere/right hand bias is excessive the loss of right hemisphere/left hand function may be significant. The results also corroborate Annett & Kilshaw (1982) with regard to mathematical ability and the strongly dextral, and replicate Kilshaw & Annett (1983) with reference to the importance of left not right hand in determining degree of dextral bias. This first study utilized a between group design which allowed comparisons to be made between mild and strong dextrals for ability and laterality differences, these are considered by Annett to be the most important comparisons because it is the degree of 'shift' to the left hemisphere/right hand which holds the key to understanding individual differences, and not its absence.

A possible criticism of this design could have been its incompatibility with the studies in the literature which have assessed handedness first and then tested for ability. Thus it could have been argued that this methodological difference may have produced a spurious experimental effect. In order to counteract such a criticism, a further analysis was carried out in which the sample were classified for handedness and then tested for ability. The results
were in full agreement with the initial findings: extent of dextral bias was inversely related to nonverbal reasoning ability.

The importance of the first study lies in the more direct comparison of the two main laterality theories. This new discovery extended previous work by Annett and her colleagues by providing for the first time, empirical evidence that excessive right hand dependence is associated with poor nonverbal ability, and further that the effects are not limited to a selected few whose lateral asymmetries and talent have been regarded as pathological in nature.

A further experimental point concerns the common practice in laterality studies of reporting data collected from students participating in psychological experiments. The main debate concerns whether such data can necessarily generalise to normal populations. Annett's principal objection to the use of such groups as sole evidence in the laterality field is that many hypotheses relating to research into individual differences in human behaviour apply to the whole of the species. Students are as valid a subject population as any other, but are nevertheless a highly select group and generally reflect a more restricted range of intelligence scores. Thus the failure to observe a high prevalence of strong dextrals in such groups is exactly what would be expected on the hypothesis of a human balanced polymorphism with heterozygote advantage; undergraduate samples include more rs+ genotypes, proportionately fewer rs++ genotypes and represent a handedness distribution that is reduced in
right hand bias relative to that of the general population. The counter argument, that the raised prevalence of left- and mixed-handers noted in occupations traditionally regarded as demanding high nonverbal abilities such as architects, mathematicians and surgeons (Geschwind & Galaburda, 1985) is pathologically determined, of course requires empirical evidence that their prevalence is significantly lower in other occupational groups before the debate can be taken any further.

The results of this first study, in conjunction with previous findings (Kilshaw & Annett, 1983; Annett & Kilshaw, 1982) suggests that nonverbal reasoning ability is significantly related to left hand weakness/right hemisphere handicap and not right hand weakness/left hemisphere handicap.

The second study addressed the question of possible relationships between reading ability and laterality. Previous studies had been interpreted within the framework of a pathology hypothesis and some support for this hypothesis was found (see page 136). One of the most basic predictions of the pathology account is that nonright-handers, due to their presumed left-hemisphere damage, are expected to be poor readers. The alternative hypothesis proposed by Annett is that there should be a quadratic relationship between reading and laterality in the population. The basic prediction is that having too much or too little of the rs+ factor carries greater risks for reading ability. The unresolved question is why this should be. The second study
provided positive evidence in favour of Annett's prediction of an inverted U function between reading and laterality: an excess of poor readers was found at opposite extremes of the laterality continuum.

Drawing principally on the reading literature, predictions were possible regarding sub-groups of poor readers within Annett’s inverted U function framework. The first lay in the expectation that the results should comply with those of Rutter, Tizard & Whitmore (1970) which identified two groups of poor readers, one who were reading below the level expected for their age but not intellect (backward), and another who were poor readers in spite of adequate intelligence (specifics). Results demonstrated that the relative reading ability of sub-groups of poor readers was significantly associated with differences for intelligence and laterality, but such findings were equivocal as the specifics were found at the dextral extreme and the backward readers at the left of the distribution, clearly in the opposite direction to that predicted. The laterality distributions of dyslexics who were below average intelligence but who were poor readers was as would be predicted if extent of right shift is inversely related to intelligence and carries risks for reading ability. Intellectually bright dyslexics however, were found in excess at the left of the laterality continuum. Without re-stating Annett’s theory, it can be seen that these results confirm her views arguing that the risks of learning difficulties in some children arise from normal variation in the biological substrate of mechanisms involved in the hemisphere function of the brain, and are not
determined by left hemisphere developmental pathology.

This somewhat contradictory evidence between the characteristics of Rutter et al's poor reading groups and the present study may lie in the point originally made by Snowling (1987) regarding differing results due to differing reading tests being used. The original Rutter et al survey employed the Neale reading comprehension test while the present investigation was limited to a test of single word recognition, this of course raises a point previously made by Bradley & Bryant (1980) that children may not understand words that they can read therefore, the reading test used is of crucial importance to our interpretation of the findings from studies of reading ability. A second possibility lies in the subsequent observation by Rutter & Yule (1975) that the intelligence of the children in the Isle of Wight study was not normally distributed, unlike the present study where the mean, median and mode for nonverbal reasoning were all at 50 thus verifying that the sample was representative of a general population.

Typically, other laterality theorists (for example Orton, 1925; 1937; Geschwind & Galaburda, 1985; Bryden, 1975) have neglected the possible implications of excessive dextral bias for intellectual performance, attention being generally focussed on the deficits and talents of the sinistral or mixed-hander. This is clearly an important omission. Annett has speculated, and these results together with others reported in the literature, support her proposal that over dependence on left hemisphere language may play a major role in determining the poor interface between auditory and visual processing directed by left and
right cerebral hemispheres. It is perhaps significant that in several discussions of reading difficulties, Boder (1973) and Frith (1975) both cite a dissociation between visual and verbal deficits in sub-groups of poor readers.

The main evidence in support of pathology accounts of poor reading has been that poor readers in the present study were found in excess among nonright-handers. However, it is also possible that this particular poor reading group were so, not because of left hemisphere pathology but because they had too little of the factor which gives speech development in the left side of the brain an extra boost, the rs+ gene. Indirectly Annett's theory is supported by work reported by Hulme (1987) from experiments investigating differences between good and retarded readers in their phonological competence. The latter's observed difficulty with phonics was considered by the author to indicate that "short term memory problems may lead to difficulties in holding partially decoded words in mind whilst they are compared with the pronunciations of words retrieved from long term memory" (page 257). It is of course possible that the two theoretical views of pathology and normal variability are in some way related: as Annett has acknowledged there may well be some sinistrals who are pathological in origin, but this suggestion for the present thesis has as far as is possible been controlled for by excluding any child whose hand skill of both hands is less than 2 s.d.s below the sample mean.

It should be noted that the failure of many studies to reproduce
Arnett's findings may not be due to the failure of the RS Theory but due to the difference in the nature of the criteria adopted for handedness. The present study observed both hand preference and hand skill whilst previous studies have used self reported hand preference as a definition of the type specified by Oldfield (1967), others are content with viewing populations as the sum of two discrete groups of right- and left-handers; and others employ several different methods of data collection: sighting eye dominance, arm folding, leg crossing, hand clasping or spreading the fingers have all failed to replicate exactly the predicted effects (Levy, 1969; Bryden, 1989; Geschwind & Galaburda, 1985). The most important difference, that of differing degrees of dextral bias is, according to Annett, impossible to observe on such criteria. As with height, handedness for Annett is not discrete but a continuous variable. This poses obvious problems when trying to make direct between study comparisons, therefore results must be viewed within the context of methodological constraints.

Having shown that sub-groups of reading ability are influenced by laterality, the question can be asked whether the distinction between dyseidetic/surface and dysphonetic/phonological dyslexics is relevant to the distinction between those having too little or too much bias to the left hemisphere/right hand in normal populations. It is, of course, a matter of continuing debate as to whether dyslexics differ qualitatively or quantitatively from normal poor readers (Bryant & Impey, 1986; Coltheart, 1987; Temple, 1987; Beech & Harding, 1984). The fact that even a few children in normal school populations have
been shown to have phonological and surface type reading deficits does however, lend support to Annett's view of different learning difficulties being part of normal variability.

On the basis of a wide range of results from the verbal and visual memory literature (see Snowling, 1987) demonstrating a confusability effect in good but not poor readers, the hypothesis of a double dissociation between tasks poorer in those at the left but not the right of the laterality continuum, and the converse, was advanced. It has been pointed out by Annett (1985) that a double dissociation would only be possible if the risks for deficit at opposite ends of the laterality distribution were causally different. Two main findings are relevant to this proposal. It was found that memory for sets of words was, as predicted, poorer in those at the left than right of the laterality continuum, but homophone discrimination (assumed to be a visuo-spatial dependent process) showed no effect for laterality. However, even in the first experiment the results cannot be taken as outright confirmation of Annett's assertions, as it could also be argued that the failure to disconfirm the hypothesis was the result of poor experimental design.

These results, particularly the second, conflict with the stated hypothesis of Annett's theory as outlined in her paper with Kilshaw (1984). No evidence for a selective visual deficit in those excessively biased to the right hand/left hemisphere relative to those reduced in right-hand bias was obtained.
This adverse evidence may be accounted for in a number of ways. The most obvious being a rejection of the RS Theory: the risks at left and right extremes of the laterality continuum did not have different causes, therefore no 'visual' effects were found. A second possibility lies in the means by which children establish the meanings of words. No effects were found because some children employ a sub-lexical route to access the lexicon of whole words and their meanings, some prefer the direct, orthographic route and access phonology at the production stage and others employ a paired associate technique with familiar words by-passing any demands on assembled phonology. A third possibility lies in the task being inappropriate for the age of the children being assessed in that the results warned of a ceiling effect for homophone discrimination. In younger children this same task may result in the predicted effect. The experimental findings do suggest the presence of a phonological deficit in those at the left but not the right extreme (a dissociation if not a double one) for laterality differences. These results support Campbell & Butterworth's (1985) and Barron & Baron's (1977) contention that verbal or visual presentation of stimuli does not control for individual differences in processing strategies.

The possibility cannot be ignored that disconfirmation of Annett's right hemisphere effect adds weight to the argument presented by Olson & Wise (1986) that efficiency in the use and manipulation of phonology depends on inherited phonological skills while lexical, orthographic procedures may ultimately depend on variation in teaching styles; for
example, some teachers rather than establishing an effective sight (whole word) vocabulary through 'look and say' teaching methods in combination with training in the phonics of a language prefer one method at the exclusion of the other. Clearly, Annett's views of the nature of right hemisphere handicap demands further empirical enquiry.

The fourth study looked at the Annett theory from a different angle. If the deficits in those at both extremes of the laterality continuum were causally different then differences in the phonological and visual spelling performance would be predicted in those at both left and right extremes of the laterality distribution (Annett, 1985). Laterality differences in the processing of visual features of written language were not found for spelling irregular, regular or nonwords. Frith (1980) did find a spelling effect for a sample size of 29 who were pre-selected for verbal intelligence and then assessed for a dissociation between good readers and good spellers, good readers and poor spellers and children poor on both. The present study used reading, spelling and laterality and had a larger sample size (sixty eight). A failure to observe significant effects in small samples may be explained in two ways: either the effect is so trivial as to need large numbers for it to become salient, or, the effect for laterality is a very sensitive one, demanding that large sample sizes are required in order to overcome the noise in the data directly attributable to the influence of chance or randomness in the development between the two sides of the brain and body and possible associations with ability. The sensitivity of orthographic effects
between good and poor readers or spellers seldom reach acceptable statistical levels of significance and there is the danger that it may be regarded as unimportant to our understanding of the reading process - which it is not - or worse, not being acknowledged at all.

What does seem an important issue, however, is the means of assessing visual-orthographic processing to measure right hemisphere function. The major criticism of the task used in the present study (homophone discrimination) is that it could have been measuring both visual and verbal processing modalities and was not a purely visual-orthographic task. It is suggested that the lack of a laterality effect is far from disproving the RS hypothesis for those excessively biased towards right-handedness and that future research should attempt to resolve the not uncommon problem in much of the current research on both laterality and the "cognitive architecture" of the reading process, of finding a pure visuo-spatial right hemisphere task. Whilst research continues to adopt a spatial ability definition of the type specified by Harris (1978), others such as Bryden (1982) warn that "More conclusive evidence that these procedures really tap functional cerebral asymmetries is needed" (cited in Annett, 1985, page 111). Geschwind & Galaburda (1985) have provided clinical evidence suggestive of a dissociation in spatial function between the cerebral hemispheres in that the left may be better at processing the fine detail of the spatial world while the right hemisphere is better at more gross spatial configurations. This poses obvious problems for the RS Theory which uses as a measure of 'right shift', right
As stated in the Introduction, the principal objective of the present research was to provide an adequate test of the RS Theory. With this aim in mind the thesis sought to make contact with several areas of psychological investigation: laterality, intelligence, reading and spelling. Investigation of the association between reading and laterality could have occupied the whole of the thesis. Theoretical considerations relating to the cognitive processes underpinning reading progress also took a back seat to the search for a double dissociation between verbal and visual deficits predicted at left and right extremes respectively, of the laterality distribution. This in no way implies that such theoretical considerations were ignored: the investigations were driven by current theorizing within the reading, speech and memory literature. However, the ultimate goal was to find new knowledge with which to explain an array of conflicting data in the laterality field between normal and clinical populations.

In summary, evidence has been found suggesting that excessive dextrality is dependent on poor left hand/right hemisphere processing and associated with poor nonverbal and verbal ability. The phonological deficits found in those at the dextral end of between hand differences are different from those at the opposite extreme of the laterality continuum. The eventual credibility of the RS Theory relies, to a great extent, upon identifying more clearly distinctions between these two 'language' factors. It is evident that in order for
Annett's theoretical predictions presented in this thesis to be supported, several problems need to be resolved: 1) the order effect apparent in the auditory perception experiment reported in Chapter 5; 2) the establishment of an unambiguous 'visuo-spatial' task; and 3) some consideration must be given to the possible effects of differing teaching styles on children's educational progress.

Other explanations to account for the superior visuo-spatial ability of the left- and mixed hander do exist. Geschwind et al (1982; 1985) have argued that the nature of left hemisphere pathology in the nonright-hander, can act to enhance the level of processing directed by the right hemisphere. The stronger the sinistrality, the superior the right hemisphere processing and, hence the more talented the visuo-spatial skills (Benbow, 1986). Clearly, such an explanation is in conflict with the present experimental findings which found that the mildly dextral, those in R-L group 2, were the most talented for nonverbal reasoning ability. Thus the present experimental evidence would argue in favour of Annett's suggestion that mild dextrality reflects an increased frequency of heterozygotes, rs+- genotypes, and minimal disadvantage to right hemisphere function.

The principal evidence in support of the RS Theory was the finding of strong dextrality being dependent on left hand weakness and not right hand speed and associated with poor nonverbal reasoning ability for both sexes. However, it is possible that this difference in ability was not due to right hemisphere handicap. Differences in the
efficiency of adjacent areas to the language cortex in the left hemisphere which play a role in nonverbal ability may be a simple alternative explanation.

In contrast to Annett's prediction of a same sex effect for nondextrals at the left extreme of the laterality continuum, the findings of the first study confirmed the previous findings of both Geschwind & Galaburda (1985) and Benbow & Stanley (1980) of sex differences in favour of males for nonverbal ability. There was no support from the fourth study for Annett's prediction of no sex differences for phonological awareness; males were worse than females at the left extreme of between hand differences for explicit awareness of phonology thus confirming the findings in the clinical literature of a raised incidence of males with language difficulties (Snowling, 1987). In support of Annett's assertion that sex differences are not expected in individuals at the left extreme of the laterality continuum, was the results of no sex differences reported in the second study of this report (the relationship between reading and laterality). However, such findings are in direct contradiction to the sex differences reported in the sinistral males noted in Chapter 1 of this report, and the robust finding of more boys to girls with reading difficulties reported in the wider literature (Rutter, Tizard & Whitmore, 1970).

In conclusion, the experimental findings reported in this thesis, have provided some new evidence in support of Annett's
theoretical position. Although there have been some difficulties and inconclusive findings the weight of such evidence is not enough to justify that the theory be abandoned. The theory is potentially able to explain a variety of conflicting experimental evidence reported in the literature on individual differences, without recourse to identifying individuals as abnormal or pathological. In the final analysis however, the ultimate value of the experimental results reported here will only be apparent by future replication.
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GALIPRET-GRAJDN,N., & AJURIAGUERRA,J. de (1951) "Trouble de l'apprentissage de la lecture et dominance laterale". Encéphale, 3, 385.


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APPENDICES
### GENOTYPE CALCULATIONS

**APPENDIX 1**

When \( rs^+ = 1.937 \) SD from mean of \( rs^- \) and incidence of left-handedness in population is 4%:

- \( rs^+ \), all right-handers and \( .0030 \) left-handed. \( rs^+ \) gene is \( .57 \) & \( rs^- \) is \( .43 \)
- \( rs^- \), all right-handers and \( .0061 \) left-handed. \( rs^+ \) \( .3249 \) \( rs^- \) \( .4902 \) \( rs^- \) \( .184 \)

Right-handers are \( rs^+ \) \( .3239 \) \( rs^- \) \( .4887 \) \( rs^- \) \( .1468 \) = .9594

Left-handers are \( rs^+ \) \( .0010 \) \( rs^- \) \( .0015 \) \( rs^- \) \( .0381 \) \( .0406 \) (as assessed overall in parental incidences in student samples)

#### RXR MATINGS

<table>
<thead>
<tr>
<th>( rs^+ \times rs^+ )</th>
<th>( rs^+ )</th>
<th>( rs^- )</th>
<th>( rs^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( rs^+ \times rs^- )</td>
<td>( .3239 )</td>
<td>( .1049 )</td>
<td>( .158290 )</td>
</tr>
<tr>
<td>( rs^- \times rs^- )</td>
<td>( .1658290 )</td>
<td>( .095097 )</td>
<td>( .071741 )</td>
</tr>
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<td>( rs^- \times rs^- )</td>
<td>( .059707 )</td>
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#### RXL & LXR MATINGS

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<td>( .3239 )</td>
<td>( .000324 )</td>
<td>( .00244 )</td>
</tr>
<tr>
<td>( rx^+ \times rx^- )</td>
<td>( .000244 )</td>
<td>( .00147 )</td>
<td>( .00243 )</td>
</tr>
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<td>( rx^+ \times rx^- )</td>
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<td>( .000110 )</td>
<td>( .009310 )</td>
</tr>
<tr>
<td>( rx^+ \times rx^- )</td>
<td>( .00015 )</td>
<td>( .012341 )</td>
<td>( .009310 )</td>
</tr>
<tr>
<td>( rx^+ \times rx^- )</td>
<td>( .00015 )</td>
<td>( .009310 )</td>
<td>( .009310 )</td>
</tr>
<tr>
<td>( rx^+ \times rx^- )</td>
<td>( .00015 )</td>
<td>( .012341 )</td>
<td>( .009310 )</td>
</tr>
<tr>
<td>( rx^+ \times rx^- )</td>
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<td>( .009310 )</td>
<td>( .009310 )</td>
</tr>
<tr>
<td>( rx^+ \times rx^- )</td>
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<td>( .012341 )</td>
<td>( .009310 )</td>
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</table>

#### LXL MATINGS

<table>
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<th>( ls^- )</th>
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<tr>
<td>( ls^+ \times ls^- )</td>
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<td>( .00001 )</td>
<td>( .00001 )</td>
</tr>
<tr>
<td>( ls^+ \times ls^- )</td>
<td>( .000015 )</td>
<td>( .000015 )</td>
<td>( .000015 )</td>
</tr>
<tr>
<td>( ls^+ \times ls^- )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
</tr>
<tr>
<td>( ls^+ \times ls^- )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
</tr>
<tr>
<td>( ls^+ \times ls^- )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
</tr>
<tr>
<td>( ls^+ \times ls^- )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
</tr>
<tr>
<td>( ls^+ \times ls^- )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
<td>( .0000016 )</td>
</tr>
</tbody>
</table>

#### PROPORTIONS

- \( .322897 \) \( .444542 \) \( .152998 \)
- \( .290437 \) \( .584350 \) \( .166223 \)
- \( .25519 \) \( .584350 \) \( .390131 \)

#### GRAND TOTAL

\( 1.00018 \)
### APPENDIX 2

#### TABLE 1 CITED IN BENBOW, 1986

<table>
<thead>
<tr>
<th></th>
<th>Mathematically precocious (SAT-M ≥ 700)</th>
<th>Verbally precocious (SAT-V ≥ 630)</th>
<th>Mathematically and verbally precocious (SAT-M ≥ 700 and SAT-V ≥ 630)</th>
<th>Fathers (N)</th>
<th>Mothers (N)</th>
<th>Brothers (N)</th>
<th>Sisters (N)</th>
<th>Male (N)</th>
<th>Female (N)</th>
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<tbody>
<tr>
<td><strong>Lehandedness among non-Asians (LQ &lt; 0) (%)</strong></td>
<td>13.8 (145)</td>
<td>5.9 (17)</td>
<td>23.3 (51)</td>
<td>12.3 (37)</td>
<td>16.7 (30)</td>
<td>20.0 (5)</td>
<td>11.4 (235)</td>
<td>8.1 (260)</td>
<td>9.1* (232)</td>
</tr>
<tr>
<td><strong>Median LQ</strong></td>
<td>75</td>
<td>67</td>
<td>60</td>
<td>78</td>
<td>75.5</td>
<td>86</td>
<td>81.8</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td><strong>Symptomatic atopic disease (%)</strong></td>
<td>53 (173)</td>
<td>54 (35)</td>
<td>52 (44)</td>
<td>48 (48)</td>
<td>54 (33)</td>
<td>14 (7)</td>
<td>45 (340)</td>
<td>44 (340)</td>
<td>40 (249)</td>
</tr>
<tr>
<td><strong>Myopia (%)</strong></td>
<td>51 (196)</td>
<td>61 (36)</td>
<td>65 (57)</td>
<td>70 (61)</td>
<td>53 (34)</td>
<td>63 (8)</td>
<td>58 (393)</td>
<td>51 (393)</td>
<td>34 (249)</td>
</tr>
<tr>
<td><strong>Age myopia was diagnosed (yr)</strong></td>
<td>9.0 (83)</td>
<td>8.5 (19)</td>
<td>8.5 (30)</td>
<td>7.8 (32)</td>
<td>9.4 (18)</td>
<td>7.4 (5)</td>
<td>17.5 (188)</td>
<td>14.2 (177)</td>
<td>9.7 (75)</td>
</tr>
</tbody>
</table>

*Handedness for siblings was self-reported.

Severity of atopic disease was assessed using a standardized instrument with the following scale: 0 = no history; 1 = isolated event, never recurring; 2 = isolated event, recurring only once; 3 = infrequently recurring problem, now inactive, no longer recurs; 4 = active, ongoing (occurrence at least once a year) problem (mild); 5 = active, ongoing problem (moderate); 6 = active, ongoing problem (severe). We accepted as a valid allergy only those given a rating of at least 3.
Appendix 4
Peg-Moving Task Norms

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Right hand Mean (sec)</th>
<th>Right hand SD</th>
<th>Left hand Mean (sec)</th>
<th>Left hand SD</th>
</tr>
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<tbody>
<tr>
<td>3½</td>
<td>26.96</td>
<td>6.95</td>
<td>29.53</td>
<td>11.97</td>
</tr>
<tr>
<td>4</td>
<td>21.83</td>
<td>2.80</td>
<td>24.19</td>
<td>6.54</td>
</tr>
<tr>
<td>4½</td>
<td>19.32</td>
<td>2.42</td>
<td>20.90</td>
<td>4.23</td>
</tr>
<tr>
<td>5</td>
<td>17.40</td>
<td>2.07</td>
<td>18.67</td>
<td>2.71</td>
</tr>
<tr>
<td>5½</td>
<td>16.35</td>
<td>1.96</td>
<td>17.56</td>
<td>2.53</td>
</tr>
<tr>
<td>6</td>
<td>15.55</td>
<td>1.75</td>
<td>16.67</td>
<td>2.29</td>
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<tr>
<td>6½</td>
<td>14.88</td>
<td>1.66</td>
<td>15.96</td>
<td>2.15</td>
</tr>
<tr>
<td>7</td>
<td>14.01</td>
<td>1.47</td>
<td>15.13</td>
<td>1.97</td>
</tr>
<tr>
<td>7½</td>
<td>13.46</td>
<td>1.39</td>
<td>14.53</td>
<td>1.86</td>
</tr>
<tr>
<td>8</td>
<td>12.65</td>
<td>1.28</td>
<td>13.69</td>
<td>1.65</td>
</tr>
<tr>
<td>8½</td>
<td>12.24</td>
<td>1.21</td>
<td>13.28</td>
<td>1.59</td>
</tr>
<tr>
<td>9</td>
<td>11.78</td>
<td>1.15</td>
<td>12.84</td>
<td>1.53</td>
</tr>
<tr>
<td>9½</td>
<td>11.34</td>
<td>1.06</td>
<td>12.35</td>
<td>1.43</td>
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<tr>
<td>10</td>
<td>10.98</td>
<td>0.97</td>
<td>11.95</td>
<td>1.34</td>
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<tr>
<td>10½</td>
<td>10.71</td>
<td>0.94</td>
<td>11.64</td>
<td>1.27</td>
</tr>
<tr>
<td>11</td>
<td>10.39</td>
<td>0.89</td>
<td>11.31</td>
<td>1.21</td>
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<tr>
<td>11½</td>
<td>10.20</td>
<td>0.89</td>
<td>11.11</td>
<td>1.16</td>
</tr>
<tr>
<td>12</td>
<td>9.95</td>
<td>0.86</td>
<td>10.83</td>
<td>1.07</td>
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<tr>
<td>12½</td>
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<td>10.78</td>
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<td>13</td>
<td>9.76</td>
<td>0.87</td>
<td>10.66</td>
<td>1.01</td>
</tr>
<tr>
<td>13½</td>
<td>9.71</td>
<td>0.85</td>
<td>10.62</td>
<td>0.99</td>
</tr>
<tr>
<td>14</td>
<td>9.65</td>
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<tr>
<td>15</td>
<td>9.61</td>
<td>0.77</td>
<td>10.58</td>
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APPENDIX 5
HAND PREFERENCE CLASSIFICATION

<table>
<thead>
<tr>
<th>Actions observed</th>
<th>Preference classes</th>
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<tbody>
<tr>
<td>A. Writing *</td>
<td>1. Right (or R+E) for all actions.</td>
</tr>
<tr>
<td>B. Throwing *</td>
<td>2. Left for any of F,G,H, only.</td>
</tr>
<tr>
<td>C. Using a racket *</td>
<td>3. Left for L and no others except above.</td>
</tr>
<tr>
<td>D. Striking a match *</td>
<td>4. Left for I and no others except above.</td>
</tr>
<tr>
<td>E. Cutting with scissors</td>
<td>5. Right writing but left for any other primary action.</td>
</tr>
<tr>
<td>F. Threading a needle</td>
<td>6. Left writing but right for any other primary action.</td>
</tr>
<tr>
<td>G. Sweeping with broom.</td>
<td>7. Left for all primary actions but right for any others.</td>
</tr>
<tr>
<td>H. Shovelling with long handled shovel</td>
<td>8. Left (or L+E) for all actions.</td>
</tr>
<tr>
<td>I. Dealing playing cards</td>
<td></td>
</tr>
<tr>
<td>J. Hammering a nail into wood *</td>
<td></td>
</tr>
<tr>
<td>K. Using a toothbrush *</td>
<td></td>
</tr>
<tr>
<td>L. Unscrewing a jar</td>
<td></td>
</tr>
</tbody>
</table>

* Primary actions: those most highly intercorrelated (Annett, 1970a)
APPENDIX 6
SPELLING LIST DERIVED FROM BODER & JARRICO (1982)

SEVENTH GRADE (LIST 7)

astronomy
doubtful
democrat
hasten
frequent
judgment
quotation
knapsack
publisher
liquor
h(ch)arity
u(a)cknowledge
s(h)andicap
t(c)ruse
d(n)evertheless
b(sc)ientific
c(r)epsentative
p(s)ergeant
n(r)evenge
ch(th)orough
Assessing Reading Difficulties: Test sheet

Name __________________________ birth date __________ age __________ test date __________
nursery rhyme __________________________ speech __________________________
language __________________________ comments __________________________

<table>
<thead>
<tr>
<th>Condition 1</th>
<th>Condition 2</th>
<th>Condition 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Last sound different</strong></td>
<td><strong>Middle sound different</strong></td>
<td><strong>First sound different</strong></td>
<td></td>
</tr>
<tr>
<td>hat mat fan cat</td>
<td>mop hop tap lop</td>
<td>rot rod rock box</td>
<td></td>
</tr>
<tr>
<td>doll hop pop top</td>
<td>pat fit bat cat</td>
<td>lick lid miss lip</td>
<td></td>
</tr>
<tr>
<td>sun gun rub fun</td>
<td>lot cot pot hat</td>
<td>bud bun bus rug</td>
<td></td>
</tr>
<tr>
<td>hen peg leg beg</td>
<td>fun pin bun gun</td>
<td>pip pin hill pig</td>
<td></td>
</tr>
<tr>
<td>fin sit pin win</td>
<td>hug dig pig wig</td>
<td>ham tap had hat</td>
<td></td>
</tr>
<tr>
<td>map cap gap jam</td>
<td>red fed lid bed</td>
<td>peg pen bell pet</td>
<td></td>
</tr>
<tr>
<td>cot hot fox pot</td>
<td>wag rag bag leg</td>
<td>fish fill fig kick</td>
<td></td>
</tr>
<tr>
<td>fill pig hill mill</td>
<td>fell doll well bell</td>
<td>mop dog doll dot</td>
<td></td>
</tr>
<tr>
<td>peel weed seed feed</td>
<td>dog fog jug log</td>
<td>seed seal deep seat</td>
<td></td>
</tr>
<tr>
<td>pack lack sad back</td>
<td>fish dish wish mash</td>
<td>room food root roof</td>
<td></td>
</tr>
</tbody>
</table>

Errors __________ Errors __________ Errors __________
ROUTE Our ROUTE was marked on the map.
SAW The man cut the wood with a SAW.
FLOWER A rose is a FLOWER.
TOW The caravan was pulled along with a TOW.
SEA The SEA was calm today.
RING The postman had to RING the doorbell.
FIR The cone fell from the FIR tree.
BOY The BOY ran for the bus.
BALL The children played with a BALL.
BEECH Jill collected sea shells on the BEACH.
FEAT The weightlifters performance was a great FEAT.
FLOOR The milk bottle fell to the FLOOR.
HEAL The wound was quick to HEAL.
OAR The rowing boat had only one OAR.
PAWS The dogs PAWS were covered in mud.
BREAD Everyone had two slices of BREAD.
WITCH The WITCH cast a spell.
TEA The lady ordered TEA to drink
WOOD The shelves were made of WOOD.
SUN Too much SUN can make you burn.
WEIGH We had to WEIGH the flour for the cake.
KNOT The scouts practiced tying a KNOT with string.
KEY The KEY was in the lock of the door.
MEAT A butcher sells MEAT.
<table>
<thead>
<tr>
<th>Appendix 9</th>
<th>Homophone Discrimination Answer Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root</td>
<td>Route</td>
</tr>
<tr>
<td>Saw</td>
<td>Sore</td>
</tr>
<tr>
<td>Flower</td>
<td>Flour</td>
</tr>
<tr>
<td>Tow</td>
<td>Toe</td>
</tr>
<tr>
<td>See</td>
<td>Sea</td>
</tr>
<tr>
<td>Ring</td>
<td>Wrang</td>
</tr>
<tr>
<td>Fur</td>
<td>Fir</td>
</tr>
<tr>
<td>Boy</td>
<td>Buoy</td>
</tr>
<tr>
<td>Bawl</td>
<td>Ball</td>
</tr>
<tr>
<td>Beech</td>
<td>Beach</td>
</tr>
<tr>
<td>Feet</td>
<td>Feat</td>
</tr>
<tr>
<td>Floor</td>
<td>Flaw</td>
</tr>
<tr>
<td>Heal</td>
<td>Heal</td>
</tr>
<tr>
<td>Or</td>
<td>Qar</td>
</tr>
<tr>
<td>Paws</td>
<td>Pause</td>
</tr>
<tr>
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## APPENDIX 10
### THE WORD ORDER TEST

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HAND EYE SKILL

APPENDIX 11

NAME

BOY — GIRL —

ARE YOU A TWIN?

YES NO

PRACTICE TEST

LEFT HAND

START

241
APPENDIX 12

AN EXAMPLE OF THE RAVENS COLOURED PROGRESSIVE MATRICES
The following publication is based on the first study reported in this thesis:

### One-Way Analysis of Variance:

#### 1. Left Peg by R-L group

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#### 2. Right Peg by R-L group

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#### 3. Ravens percentiles by R-L group

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#### 4. RQ x R-L group

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#### 5. Reading Stresid x R-L group

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#### 6. Bradley & Bryant (BBzresid) x R-L Group

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#### 7. Bradley & Bryant (CFMzresid) x R-L group

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#### 8. Word Order Errors x R-LL group

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### 9. Homophone Errors x R-LL group

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#### TWO-WAY ANALYSIS OF VARIANCE

### 10. LPegst x R-L x Sex

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### 11. RPegst x R-L x Sex

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### 12. Ravens Percentiles x R-L x Sex

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### 13. RQ x R-L x Sex

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**2-Way Interactions**

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### 14. Reading Stresid x R-L x Sex

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**2-Way Interactions**

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### 15. Word Order Errors x R-LL x Sex

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**2-Way Interactions**

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<tr>
<td>Total</td>
<td>137</td>
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### 16. Homophone Errors x R-LL x Sex

<table>
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<tr>
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<tbody>
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<td>3.647</td>
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**2-Way Interactions**

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<tbody>
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### 17. Bradley & Bryant (BBzresid) x R-L group x Sex x Reading Group

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<tbody>
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<td>.006</td>
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2-Way interactions

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<td>.765</td>
<td>.950</td>
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3-Way Interactions

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</tr>
</thead>
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Explained: 15
Residual: 39
Total: 54

### 18. Bradley & Bryant (CFMzresid) x R-L group x Sex x Reading Group

<table>
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<tbody>
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<td>.062</td>
<td>.077</td>
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<tr>
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2-Way Interactions

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</thead>
<tbody>
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<td>.951</td>
<td>.426</td>
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3-Way Interactions

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<td>R-L x Sex x Reading Group</td>
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Explained: 15
Residual: 39
Total: 54

### 19. Syllables x R-L group x Reading group

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<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main effects</td>
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<td>169.267</td>
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<tr>
<td>R-L</td>
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2-Way Interactions

<table>
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<tbody>
<tr>
<td>R-L x Reading group</td>
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Explained: 7
Residual: 60
Total: 67

247
20. Consonants x R-L group x Reading group

<table>
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<tbody>
<tr>
<td>Main effects</td>
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<td>1.059</td>
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<td>279.138</td>
<td>279.138</td>
<td>24.986</td>
<td>≤.0001</td>
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</table>

2-Way Interactions

| R-L x Reading group  | 3  | 22.418 | 7.473 | .669   | .574    |

Explained

<table>
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<tr>
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<tbody>
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21. Vowels x R-L group x Reading group

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<th>P</th>
</tr>
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</tbody>
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2-Way Interactions

| R-L x Reading group  | 3  | 54.248 | 18.083 | 1.958  | .130    |

Explained

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<th>P</th>
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<tbody>
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22. Plausible Pronunciations x R-L group x Reading group

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2-Way Interactions

| R-L x Reading group  | 3  | 36.342 | 12.114 | 1.481  | .229    |

Explained

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</table>

MANOVA'S

23. LPegst, R Pegst x Bradley & Bryant (BBzresid) (CFMzresid)

<table>
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<tr>
<td>R Pegst</td>
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<td>448.48</td>
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<td>3.75</td>
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Within cells

<table>
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<td>448.48</td>
<td>3.75</td>
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<td>R Pegst</td>
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<td>448.48</td>
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248
### 24. Confusable, Nonconfusable words x R-LL x Sex

<table>
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### 25. Vowels, Syllables, Consonants, Plausible Pronunciations x R-L Group

<table>
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### 26. Analysis of Covariance Plausible Pronunciations, Ravens Percentiles x R-L group

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<th>SE</th>
<th>T</th>
<th>P</th>
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### 27. Syllables (Reg. + Irreg. Words) x R-L x Sex

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### 28. Vowels (Reg. + Irreg. Words) x R-L x Sex

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### 29. Consonants (Reg. + Irreg. Words) x R-L x Sex

<table>
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<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
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<td>.87</td>
<td>.36</td>
<td>.551</td>
</tr>
<tr>
<td>R-L x Sex</td>
<td>3</td>
<td>3.26</td>
<td>1.09</td>
<td>.45</td>
<td>.720</td>
</tr>
</tbody>
</table>

### 30. Plausible Pronunciations (Reg. + Irreg. Words) x R-L x Sex

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within cells</td>
<td>60</td>
<td>157.60</td>
<td>2.763</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1</td>
<td>603.54</td>
<td>603.54</td>
<td>229.77</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>R-L</td>
<td>3</td>
<td>4.45</td>
<td>1.48</td>
<td>.56</td>
<td>.641</td>
</tr>
<tr>
<td>R-L x Sex</td>
<td>3</td>
<td>6.13</td>
<td>2.04</td>
<td>.78</td>
<td>.511</td>
</tr>
</tbody>
</table>

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31. Stepwise regression, Reading Age (RA), Chronological age (CA), Ravens’ Matrices raw scores and first language at home English Multiple R R Square S Error.

Dependent variable: RA

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>-6.759472</td>
<td>4.309198</td>
<td>-.050645</td>
<td>1.569</td>
<td>.1177</td>
</tr>
<tr>
<td>Ravens</td>
<td>1.513887</td>
<td>.205063</td>
<td>.327758</td>
<td>7.383</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>CA</td>
<td>.719454</td>
<td>.059079</td>
<td>.541738</td>
<td>12.178</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>(Constant)</td>
<td>4.634192</td>
<td>6.317223</td>
<td></td>
<td>.734</td>
<td>.4637</td>
</tr>
</tbody>
</table>

32. Stepwise regression, Bradley & Bryant rhyming correct and CA Multiple R R Square S Error.

Dependent variable: Bradley & Bryant Rhyming

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>.71134</td>
<td>.042156</td>
<td>.711339</td>
<td>7.368</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-15.281534</td>
<td>3.504771</td>
<td></td>
<td>4.360</td>
<td>.0001</td>
</tr>
</tbody>
</table>

33. Stepwise regression, Bradley & Bryant rhyming correct, CA and Ravens Percentiles Multiple R R Square S Error.

Dependent variable: Bradley & Bryant Rhyming

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens</td>
<td>.311612</td>
<td>.042190</td>
<td>.713631</td>
<td>7.386</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>CA</td>
<td>-16.173084</td>
<td>3.624237</td>
<td></td>
<td>4.462</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

34. Stepwise regression, CA, Ravens Percentiles, RQ and Bradley & Bryant rhyming correct Multiple R R Square S Error R Change Signif.

Dependent variable: Bradley & Bryant Rhyming

1. CA .72780 .52970 3.08993 .52970 <.0001
2. Ravens .73618 .54491 3.06756 .01521 .1847
3. RQ .77842 .60594 2.88126 .06103 .0060

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>.308971</td>
<td>.015908</td>
<td>.094024</td>
<td>.973</td>
<td>.3350</td>
</tr>
<tr>
<td>Ravens</td>
<td>.311612</td>
<td>.042190</td>
<td>.713631</td>
<td>7.386</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>RQ</td>
<td>-16.173084</td>
<td>3.624237</td>
<td></td>
<td>4.462</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-22.238097</td>
<td>3.656014</td>
<td></td>
<td>-6.083</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
### 35. Stepwise regression, CA, Ravens Percentiles, R-L, Bradley & Bryant rhyming correct

<table>
<thead>
<tr>
<th>Multiple R</th>
<th>R Square</th>
<th>SError</th>
<th>R Change</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>.72780</td>
<td>.52970</td>
<td>3.08993</td>
<td>.52970</td>
</tr>
<tr>
<td>Ravens</td>
<td>.73818</td>
<td>.54491</td>
<td>3.06756</td>
<td>.01521</td>
</tr>
<tr>
<td>R-L</td>
<td>.76332</td>
<td>.58266</td>
<td>2.96517</td>
<td>.03775</td>
</tr>
</tbody>
</table>

Dependent variable: Bradley & Bryant Rhyming

Variables in the equation:

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>.315290</td>
<td>.040132</td>
<td>.701891</td>
<td>7.856</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Ravens</td>
<td>.021168</td>
<td>.015005</td>
<td>.125264</td>
<td>1.411</td>
<td>.1642</td>
</tr>
<tr>
<td>R-L</td>
<td>.055346</td>
<td>.025279</td>
<td>.195489</td>
<td>2.189</td>
<td>.0330</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-19.633013</td>
<td>3.497608</td>
<td>5.613</td>
<td>&lt;.001</td>
<td></td>
</tr>
</tbody>
</table>

### 36. Stepwise regression, Sex, CA, English test score, R-LL and Word order errors

<table>
<thead>
<tr>
<th>Multiple R</th>
<th>R Square</th>
<th>SError</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>.42747</td>
<td>.18273</td>
</tr>
<tr>
<td>Sex</td>
<td>.45413</td>
<td>.20623</td>
</tr>
</tbody>
</table>

Variables in the equation:

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>-.099508</td>
<td>.01191</td>
<td>-.419957</td>
<td>5.470</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sex</td>
<td>-.935499</td>
<td>.467983</td>
<td>-.153467</td>
<td>1.999</td>
<td>.0476</td>
</tr>
<tr>
<td>(Constant)</td>
<td>14.317030</td>
<td>1.947154</td>
<td>7.353</td>
<td>&lt;.001</td>
<td></td>
</tr>
</tbody>
</table>

Variables not in the equation:

| CA       | -.050758 | .652   | .5155 |
| R-LL     | -.113016 | 1.452  | .1488 |

### 37. Stepwise regression, Sex, CA, English test score, ILLines, RLines, and Homophone errors

<table>
<thead>
<tr>
<th>Multiple R</th>
<th>R Square</th>
<th>SError</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>.52977</td>
<td>.28066</td>
</tr>
<tr>
<td>CA</td>
<td>.55255</td>
<td>.30531</td>
</tr>
<tr>
<td>Sex</td>
<td>.57169</td>
<td>.32683</td>
</tr>
</tbody>
</table>

Variables in the equation:

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>-.083588</td>
<td>.011014</td>
<td>-.537961</td>
<td>7.589</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>CA</td>
<td>-.050501</td>
<td>.020242</td>
<td>-.178558</td>
<td>2.495</td>
<td>.0138</td>
</tr>
<tr>
<td>Sex</td>
<td>-.592441</td>
<td>.285196</td>
<td>-.148317</td>
<td>2.077</td>
<td>.0397</td>
</tr>
<tr>
<td>(Constant)</td>
<td>17.723769</td>
<td>2.988239</td>
<td>5.931</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

Variables not in the equation:

| ILLines   | -.117897 | 1.613   | .1092 |
| RLines    | -.074849 | -.973   | .3322 |
38. Stepwise regression, Sex, CA, RA, Ravens percentiles, R-L, LPegst, RPegst, Plausible pronunciations

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>Plausible pronunciations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>R Square</td>
</tr>
<tr>
<td>1. Sex</td>
<td>.01713</td>
</tr>
<tr>
<td>2. CA</td>
<td>.30047</td>
</tr>
<tr>
<td>3. RA</td>
<td>.74060</td>
</tr>
<tr>
<td>4. Ravens</td>
<td>.74091</td>
</tr>
<tr>
<td>5. R-L</td>
<td>.74191</td>
</tr>
<tr>
<td>6. LPegst</td>
<td>.76776</td>
</tr>
<tr>
<td>7. RPegst</td>
<td>.76925</td>
</tr>
</tbody>
</table>

Variables in the equation:

<table>
<thead>
<tr>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>.507486</td>
<td>.391422</td>
<td>.113329</td>
<td>1.297</td>
</tr>
<tr>
<td>CA</td>
<td>.040537</td>
<td>.057373</td>
<td>.064294</td>
<td>.707</td>
</tr>
<tr>
<td>RA</td>
<td>.087526</td>
<td>.012022</td>
<td>.743991</td>
<td>7.280</td>
</tr>
<tr>
<td>Ravens</td>
<td>.006097</td>
<td>.008897</td>
<td>.067709</td>
<td>.685</td>
</tr>
<tr>
<td>R-L</td>
<td>-.268308</td>
<td>.404765</td>
<td>-1.411330</td>
<td>-0.663</td>
</tr>
<tr>
<td>LPegst</td>
<td>-.275386</td>
<td>.409660</td>
<td>-1.920798</td>
<td>-0.672</td>
</tr>
<tr>
<td>RPegst</td>
<td>.237065</td>
<td>.409352</td>
<td>1.345936</td>
<td>0.579</td>
</tr>
<tr>
<td>(Constant)</td>
<td>2.094511</td>
<td>18.046016</td>
<td>0.116</td>
<td>.9080</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>Syllables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>R Square</td>
</tr>
<tr>
<td>1. Sex</td>
<td>.05992</td>
</tr>
<tr>
<td>2. CA</td>
<td>.19926</td>
</tr>
<tr>
<td>3. RA</td>
<td>.58362</td>
</tr>
<tr>
<td>4. Ravens</td>
<td>.59493</td>
</tr>
<tr>
<td>5. R-L</td>
<td>.60754</td>
</tr>
<tr>
<td>6. LPegst</td>
<td>.60783</td>
</tr>
<tr>
<td>7. RPegst</td>
<td>.63953</td>
</tr>
</tbody>
</table>

Variables in the equation:

<table>
<thead>
<tr>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>-.096791</td>
<td>.425372</td>
<td>-.023931</td>
<td>-0.228</td>
</tr>
<tr>
<td>CA</td>
<td>.019134</td>
<td>.062349</td>
<td>.033599</td>
<td>.307</td>
</tr>
<tr>
<td>RA</td>
<td>.057808</td>
<td>.013065</td>
<td>.544028</td>
<td>4.425</td>
</tr>
<tr>
<td>Ravens</td>
<td>.011855</td>
<td>.009669</td>
<td>.145762</td>
<td>1.226</td>
</tr>
<tr>
<td>R-L</td>
<td>.904424</td>
<td>.439872</td>
<td>5.267050</td>
<td>2.056</td>
</tr>
<tr>
<td>LPegst</td>
<td>.894608</td>
<td>.445192</td>
<td>6.908330</td>
<td>2.009</td>
</tr>
<tr>
<td>RPegst</td>
<td>-.891303</td>
<td>.448486</td>
<td>-5.602515</td>
<td>-2.004</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-38.566631</td>
<td>19.611216</td>
<td>-1.967</td>
<td>.0539</td>
</tr>
</tbody>
</table>

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### 41. Stepwise regression, Sex, CA, RA, Ravens percentiles, R-L, L Pegst, R Pegst and consonants

<table>
<thead>
<tr>
<th>Multiple R</th>
<th>R Square</th>
<th>SError</th>
<th>R Change</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Dependent variable:** Consonants

1. **Sex**
   - Multiple R: 0.07618
   - R Square: 0.00580
   - SError: 2.15746
   - R Change: 0.00580
   - Signif.: 0.5369

2. **CA**
   - Multiple R: 0.15140
   - R Square: 0.02292
   - SError: 2.15520
   - R Change: 0.01712
   - Signif.: 0.2899

3. **RA**
   - Multiple R: 0.68418
   - R Square: 0.46810
   - SError: 1.60252
   - R Change: 0.44518
   - Signif.: <0.001

4. **Ravens**
   - Multiple R: 0.68736
   - R Square: 0.47247
   - SError: 1.60854
   - R Change: 0.00437
   - Signif.: 0.4728

5. **R-L**
   - Multiple R: 0.73425
   - R Square: 0.53912
   - SError: 1.51557
   - R Change: 0.06666
   - Signif.: 0.0039

**Variables in the equation**

<table>
<thead>
<tr>
<th>B</th>
<th>SE B</th>
<th>Beta</th>
<th>T</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>0.425451</td>
<td>0.367422</td>
<td>0.099403</td>
<td>1.158</td>
</tr>
<tr>
<td>CA</td>
<td>-0.054366</td>
<td>0.053855</td>
<td>-0.090215</td>
<td>1.008</td>
</tr>
<tr>
<td>RA</td>
<td>0.091982</td>
<td>0.011285</td>
<td>0.818020</td>
<td>8.151</td>
</tr>
<tr>
<td>Ravens</td>
<td>-2.44215E-04</td>
<td>0.008352</td>
<td>-0.002837</td>
<td>-0.029</td>
</tr>
<tr>
<td>R-L</td>
<td>1.22176</td>
<td>0.379947</td>
<td>6.175690</td>
<td>2.954</td>
</tr>
<tr>
<td>L Pegst</td>
<td>1.080828</td>
<td>0.384542</td>
<td>7.887257</td>
<td>2.811</td>
</tr>
<tr>
<td>R Pegst</td>
<td>-1.102079</td>
<td>0.384253</td>
<td>-6.546349</td>
<td>-2.868</td>
</tr>
<tr>
<td>(Constant)</td>
<td>-45.199591</td>
<td>16.939537</td>
<td>-2.668</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

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