Aspects of Phonological Processing in Sub-groups of Left and Right Handedness

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Contents

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Abstract

This thesis was begun with two intentions. The first was to test a hypothesis of the Annett Right Shift Theory (1972, 1985) that people with poor phonology are less biased to right-handedness than the general population. The second was to establish whether a reduced bias to dextrality applies to deficits in all types of phonological processing.

Evidence for an association between poor phonological processing and reduced dextrality was demonstrated in an age cohort of schoolchildren and in two large undergraduate samples. Cases of 'pathological' handedness are unlikely to have caused the association as, in children, the differences increased when those with slow hand skill and poor vocabularies were removed. Support for a genetic influence upon phonological processing was found when groups of children and undergraduates with varying phonological ability also varied for their relatives' handedness.

Although, as expected, undergraduates with problems with nonword rhyme were more often left-handed and had more left handed relatives, against predictions, those with phoneme discrimination difficulties were much more dextral in handedness and had fewer left handed relatives. These interesting results were further investigated and poor ability in either phonological production/segmentation or rhyme/awareness was found to be associated with a reduced shift to dextrality. Finally an atypical pattern in dichotic listening (equal errors at each ear) was associated with phonological awareness difficulties, as was the atypical pattern of absence of shift to dextrality in handedness.

The findings suggest that poor phonological awareness or phonological production/segmentation could be at risk in the rs—genotype and minor phoneme perception problems could be a disadvantage for the rs++ genotype. It is also suggested that the latter could be part of a multi-sensory problem (Stein and Walsh, 1997). These questions are discussed further and the contributions, limitations and implications of the work are reviewed.

Preface

Work on this thesis began in 1992, during my employment as a research assistant to Dr. Marian Annett, working on a project supported by the Welcome Trust. The main purpose of the project was to test a major hypothesis of the Right Shift theory (Annett, 1972, 1985). This hypothesis predicts the existence of at least two types of dyslexia and that groups of affected individuals will differ from each other and the rest of the population in laterality. The project began with Dr. Annett collecting data from schools, in a first round of testing. In this she was helped by a previous assistant who soon left and was replaced by two part-time assistants, Elizabeth Eglinton and myself . Consequently the first year tasks used in the schools were selected and administered before our arrival but analysis had not yet begun. Nevertheless the first year data, which uniquely involved the entire cohort, were then available for our separate and combined analyses. From the beginning, we (Eglinton and Smythe) had independent briefs to concentrate on different issues concerning the RS Theory.

The second year gave both assistants a first opportunity to introduce tests with their own particular research interests in mind. Most tests were planned by Annett but Eglinton included a test of visual memory and I (Smythe) adapted a test of phoneme segmentation (based on Stuart, 1991 and Bruce, 1956). Further opportunity to pursue our own research interests arose in the third year of data collection. Eglinton designed a specific test of spelling of the 'ee' sound and included tests of homophone discrimination, a repeat spelling test and a computer based test of letter discrimination. I adapted tests of phoneme discrimination, nonword repetition and a computer-based test of homophone recognition besides including a test of digit span. Again the remaining tests were planned by Annett. One paper, referred to later in the text, has been published so far on the work (Annett, Eglinton & Smythe, 1996) but more are expected to follow from the analyses of all three researchers.

In years two and three, all three experimenters (Annett, Eglinton and Smythe) were involved in the administration of all tasks. Second year tasks included a large proportion of the sample whereas year three tasks involved a very selected group of participants who were chosen precisely because they had unusual results on earlier tests. Again data from all tests (Wellcome data file) were available for all three experimenters to analyse separately and combined.

In addition to the school sample it was possible to test hypotheses on large numbers of unselected undergraduate volunteers who were available as subjects for project work in the psychology department. Annett, Eglinton and Smythe again co-operated, as part of third year student projects, in the presentation and scoring of class tasks (Word data files). Eglinton was responsible for a spelling test and the specific 'ee' sound spelling test while I (Smythe) was responsible for tasks of nonword spelling, phoneme discrimination and nonword rhyme recognition.

The investigation of some hypotheses, for this thesis, required the individual testing of undergraduate volunteers (Spooner data file), an exercise, which was performed by me. Tasks of auditory acronym production, phoneme discrimination, and nonword rhyme recognition were presented together with other tests that had previously been used by Annett (1991). However this sample was selected and designed to include three groups of approximately equal numbers of subjects with differing handedness (left, pure right and mixed right).

Consequently, data from three independent sets (Wellcome, Spooner and Word) were available for the analyses in this thesis. All tasks used in the three projects are listed in the methodology section and further details are given in the appropriate sections.

Chapter 1

Literature Review

This thesis has two main purposes. The first was to test a hypothesis of the Annett Right Shift (RS) Theory that people with poor phonology are less biased to right-handedness than the general population. The second was to investigate whether a reduced bias to dextrality applies to deficits in all types of phonological processing, to one specific component of phonological processing or to several specific components. The first hypothesis stems from the RS Theory but Annett has not specified which type of phonological processing might be at risk so in order to investigate this question, different aspects of phonological processing had to be distinguished. Consequently this work has a bearing on several large fields of research interest i.e. cerebral dominance, handedness, dyslexia, the development of reading and spelling and the importance of various aspects of phonological processing.

This first chapter reviews the background literature against which later research work was developed but as it covers so many fields of research the review has been divided into two. Part one concerns the literature on cerebral dominance, handedness and dyslexia while part two reviews various aspects of phonological processing and literacy.

Part 1: Cerebral Dominance, Handedness, Dyslexia and the Development of Literacy.

It is approximately a century and a half since Broca suggested that loss of articulate speech was usually associated with lesions in the left cerebral hemisphere (in the region now known as "Broca's area"). This association was later corroborated and increased to include a link between more posterior lesions of the left hemisphere (LH), Wernicke's area, and the loss of receptive language. An early assumption that the right hemisphere (RH) was unimportant for mental processes gave way to recognition that both hemispheres are influential and complementary. This has become an important question of research interest in neuropsychology.

Broca's discovery led to the hypothesis that the hemisphere that was specialized for language could also be dominant for motor function (i.e. left handedness would be associated with RH speech). This was demonstrated to be untrue by evidence that LH lesions often accompanied aphasia in left-handers as well as right-handers (Goodglass and Quadfasel, 1954; Ettlinger et al. 1956). However there does seem to be some relationship between handedness and cerebral lateralization. Although most left and right-handers have LH representation for language, atypical cerebral lateralization is found more frequently in left-handers (Alekoumbides, 1978; Conrad, 1949; Subirana, 1958; 1969; Gloning et al., 1969; Gloning, 1977; Luria, 1970 and Satz, 1979; Kimura, 1983).

Orton (1925) was one of the first people to suggest a connection between laterality and reading. He hypothesised that delays in neurological development prevented the formation of a dominant cerebral hemisphere, which caused confusion of visual images processed by both sides of the brain (e.g. "b" and "d"). Orton proposed that both failure to develop a clear hand preference and lack of correlation between eye and hand preference was evidence of an absence of cerebral dominance. However since then many studies have concluded that evidence for a link is unsatisfactory (Satz and Fletcher, 1987; Zeman, 1967). Several clinical studies have supported Orton's observations that children with developmental language problems include a large proportion with no consistent right-sided preferences (Hallgren, 1950 Harris, 1957; Zangwill, 1962; Naidoo, 1972) but other population studies have not (Clark, 1970; Rutter, Tizard & Whitmore, 1970; Hardyck & Petrinovitch, 1977). Several reviews have concluded that evidence for a link between handedness and the development of literacy is unconvincing (Bishop, 1990b; Rutter & Yule, 1975; Satz & Fletcher, 1987; Zeman, 1967). This has led to general rejection of the idea of an association between atypical laterality and specific reading difficulties. (The use of terms such as specific reading difficulties and dyslexia will be discussed in more detail later but briefly they refer to children with no apparent evidence of neurological abnormalities who nevertheless find great difficulty in learning to read and spell in spite of normal intelligence and adequate opportunities to learn.)

It has been suggested that the belief in an association between left-handedness and ability resulted from the influence of small scale and poorly conducted clinical studies that were open to sampling bias (Hardyck and Petrinovich, 1977). When a sample of dyslexic children is compared with an equal number of controls there are several problems. Bias can occur when the purpose of a study is known and "interesting" (i.e. non-right handed) cases are referred. It is also possible that poor readers who are left-handed are more likely to be referred to clinics because left-handedness is believed to indicate an unusual and possibly unfavourable neurological organization. An assumption that left-handedness is linked with dyslexia could also cause the diagnosis to be made more often for a left-handed poor reader. This type of bias should be avoided by using samples from a well-defined population (i.e. all children attending a particular school or schools as in the Wellcome sample used in this thesis).

Bishop (1983) makes the further point that in a population sample any condition with a low base rate would result in differences between left- and right-handers being very small and consequently difficult to detect. She states that, although a study by Rutter, Tizard & Whitmore (1970) was quite large scale, (107 retarded readers and 125 controls with 29% and 19% mixed or left handers, respectively) it was not powerful enough to distinguish between a true difference in the rate of left-handedness and one due to sampling error (Bishop, 1990b). However the Wellcome sample used in this work is considerably larger (including almost 500 children).

In 1990 Bishop identified studies, with tight criteria for the diagnosis of dyslexia and the assessment of handedness for a meta-analysis. She excluded all studies that lacked information about reading level or IQ and any that included children with very mild difficulties (reading level had to be well below both chronological and mental age). Only 25 studies, with objective measures of handedness and control data were included. Following suggestions of Hunter et al., (1982) she counted significant and nonsignificant findings to show that only two of the 25 were statistically significant. Combining data from the studies found 11.3% left handedness in dyslexics and 10.6% in controls (non-significant). Finally, removing data from the large National Child Development Study (Bishop, 1984), because large-scale studies with many experimenters have a greater chance of error in data scoring and coding, found an overall rate of left-handedness of 11.2% in dyslexics and 5.8% in controls. Although this was a statistically significant difference Bishop suggested that it was too small to justify overall support for an association between handedness and dyslexia. However Rutter, Tizard & Whitmore's results were also close to these estimates. This difference, though, is as would be predicted by the RS theory (described below) if, as expected, phonological dyslexics are less shifted to the right while other dyslexics are strongly right handed.

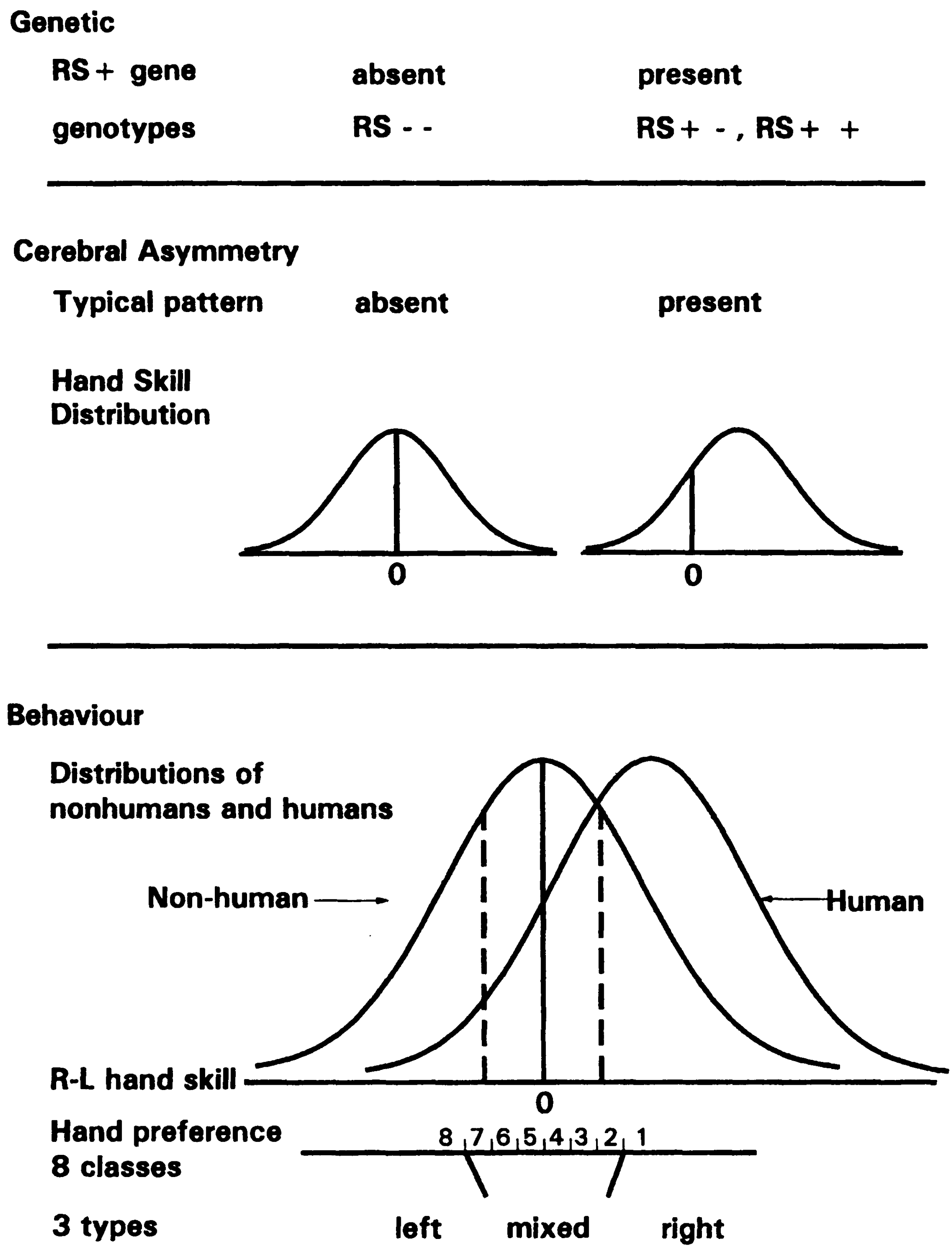
Eglinton & Annett (1994) re-analysed the same studies as Bishop (1990) but using newer methods of meta-analysis (recommended by Rosenthal, 1991). They found a small, but reliable, increase in the proportion of non-right handers amongst dyslexics, as predicted by the Annett right shift theory of handedness. Effects were examined for two different classifications, right versus mixed plus left-handers and left versus right plus mixed-handers with statistically significant effects being found for both. In individual studies effect sizes were small but over many studies the trends were consistent. Findings were as expected if dyslexics include a higher proportion of non-right handers than controls although the effects are weak because different sub-types of dyslexics were not differentiated.

The Annett Right Shift Theory.

The Annett Right Shift Theory (Annett, 1972, 1985) is a theory of cerebral dominance, which presents a possible resolution to the handedness and dyslexia controversy. It is a theory of cerebral dominance in which handedness is not causal but one of effect. Figure 1.1 (Annett, 1995a) illustrates the development of the RS theory as a series of levels of analysis (based on a method suggested by Morton & Frith, 1995).

Beginning from the bottom of figure 1.1 and progressing upwards the first level concerns behavioural aspects of the RS Theory and the important issue of mixed handedness. A considerable problem in handedness research has long been the variety of indices of measurement used in different studies. However this situation could be simplified by the use of Annett's continuum of hand preference linked to a continuum of hand skill. Annett, Lee and Ounsted (1961) separated mixed handers (who reliably use the right hand for some actions and the left for others) from consistent handers (both L and R) finding the three groups of left, right and mixed handers to be in approximately binomial proportions (Annett, 1967). Sub-groups of hand preference were based on empirical evidence for differences in hand skill for peg moving (Annett, 1970a; 1976; 1985) and the order of subgroups was found to be consistent for four other tests of hand skill (Annett, 1992).

Figure 1.1 Level of analysis



Consequently a reliable association between mixed handedness and degrees of hand skill asymmetry was demonstrated. This system of sub-group classification (continuous, not discrete) was shown to be a strong basis for analysing levels of right and left hand preference (Annett, 1970a; 1976) and it will be used as such in this thesis. (A decision tree for subgroup classification is included in appendix A. Right-handed sub-groups are consistent right (1) and mixed right-handers (2, 3 and 4 have weak, moderate and strong left tendencies respectively). Left-handed sub-groups are consistent left (8) and mixed left-handers (7 and 6 have weak and strong right tendencies respectively). The original class 5 was re-assigned to classes 3 and 4 (see Annett 1985).

Annett demonstrated not only a link between the continuum of hand preference and hand skill but also that R-L hand skill for peg moving, in the population, forms a normal distribution. In 1972 Annett suggested common thresholds for *mixed* "handedness/pawedness" in both humans and non-humans, but at different positions along the continuum of skill. In non-humans proportions were 25, 50, 25 percent, while in humans they were 4, 66, 30 percent, (pure left, mixed and pure right respectively). Collins (1969; 1970) demonstrated that left paw preferences can arise by chance, in mice, and Annett proposed a similar situation in humans when the factor, which encouraged dextrality, was missing. She suggested a random basis for human lateral asymmetries plus one systematic influence that increases the chance of dextrality in handedness. This influence, however, *does not cause* either dextrality or sinistrality but merely increases the probability of right-handedness. Consequently, strong random sinistrality is reduced but not prevented when the influence is present so some left-handers will carry the rs+ gene (see overlapping distributions).

The second level in figure 1.1 illustrates the implications of the RS Theory for cerebral asymmetry of speech. Annett proposed that the shift to the right hand is associated with a left hemisphere (LH) advantage for speech. Although the majority of individuals have standard cerebral dominance for speech and a handedness distribution that is shifted to the right, Annett proposed that a minority, who do not have the typical cerebral dominance for speech, would lack the RS factor. This minority would have a handedness distribution that is not shifted to dextrality, having a mean R-L of 0 (R=L). As hand preference would arise by chance there would be equal numbers in this minority with superior right hands and superior left hands. However, social and cultural pressures would be expected to influence many individuals with RH speech to write with their right hands so that groups of individuals with right hemisphere (RH) speech would include more right than left writers.

The third level of figure 1.1 illustrates the genetic influence of the RS factor (the rs+ gene), which was proposed by Annett in 1978b. Individuals with RH speech are expected to lack the factor that encourages the shift to dextrality (rs-- genotype). In 1985 the percentage of the population as a whole, irrespective of handedness, with RH speech was calculated using data from several different sources. All studies which were selected for handedness or lesion laterality and any cases of speech disorder of articulation only (Penfold & Roberts, 1959) were excluded from the analysis. This left four studies of dysphasics (Conrad, 1949; Newcombe & Ratcliffe, 1973; Bingley, 1958; and Hecaen & Ajuriaguerra, 1964) that were very consistent and in combination identified 9.27% of the population as having RH speech. If RH speech indicates the rs-- genotype and 50% have LH speech by chance then 18.54% of the population would be rs-- genotype. Calculations using the Hardy-Weinberg equation for population genetics revealed the following gene frequencies, 0.43 for rs- (square root of 0.1854) and 0.57 for rs+ (1 - 0.43). Annett (1978b; 1985) has shown that these gene and genotype frequencies can account for handedness in families.

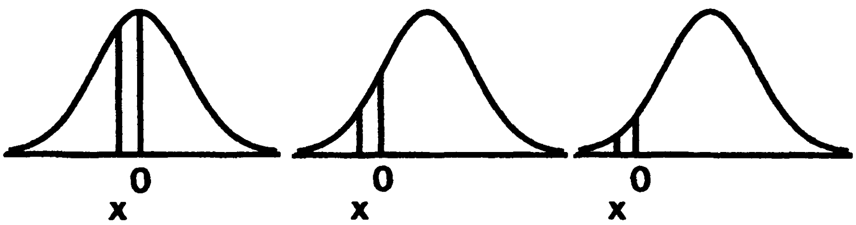
The proportion of rs+- genotypes is almost as high as is possible for a single gene locus (and both homozygotes are smaller, but sizable). Annett suggested that the rs+ gene could be held, in the population, in a balanced polymorphism with heterozygote advantage (BP + HA). In such a balanced polymorphism the heterozygote condition (rs+-), of a gene, has a selective advantage over both homozygous conditions (rs++ and rs--). This led to a search for the advantage and disadvantage associated with each genotype. The RS Theory makes several predictions and these are shown in figure 1.2 (Annett, 1995a). Reading from the top the first level illustrates predictions for the genetic proportions of the three genotypes. These are expected to be in the proportions of rs-- 0.1854, rs+- 0.4904 and rs++ 0.3242.

The second level shows the expected patterns of cerebral dominance for each genotype, as each is associated with different degrees of LH and RH advantage. In normal development the rs+ gene *always* induces typical cerebral dominance when it is present (the rs+- and rs++ genotypes) while cerebral specialization is random when it is absent (the rs-- genotype). It is possible that an additive effect exists for the mechanisms that influence the degree of cerebral asymmetry and handedness so that both are more strongly expressed in the rs++ genotype than the rs+- genotype. Annett (1978) has proposed an over commitment to the left hemisphere at the expense of right hemisphere functions as the disadvantage for gene carriers. Individuals with two copies of the gene might suffer a greater over commitment. LH advantage coupled with RH disadvantage is expected in gene carriers but not in non-gene-carriers. This is supported by findings of Annett and Kilshaw (1983) that strong right-hand preferences, especially in females, are associated with weak left hand skills.

Level three shows the implications for cognitive abilities that are expected for the three genotypes. Gene carriers are expected to have cognitive advantages associated with the development of speech lateralization. If speech output and input both predominantly involve the same hemisphere a short, reliable feedback route is available when speech is acquired. If, in contrast, separate hemispheres are involved a longer pathway with extra crossings of the immature corpus callosum would result. This could lead to difficulties when developing cognitive representations of the relationships between sounds and phonemes so that problems emerge later when literacy skills are learned. The risk of phonological problems is greatest in the rs-- genotype but not all of these would suffer disadvantage, as some would be normally lateralized by chance. Annett (1991) suggested that the critical developmental variable could be whether speech output and input have a reliable feedback loop, which is more likely if they are controlled from the same side of the brain. If the cerebral laterality of these two is random then four combinations of speech input and output are possible with two of these (approximately 50%) expected to be at risk for speech processing difficulties. Twenty five percent of the rs-- genotype would be expected to develop all speech processing together in the L hemisphere and would not be anticipated to be at risk for deficits in phonological processing. This subgroup of the rs-- genotype is expected to enjoy both the advantage of optimal

Figure 1.2 Level of analysis

Genetic			
genotype	RS - -	RS + -	RS + +
proportions	.1854	.4904	.3242
Cerebral			
left hemisphere advantage	absent	moderate	strong
right hemisphere disadvantage	absent	moderate	strong
Cognitive			
risks to phonology	present	absent	absent
risks to visuospatial	absent	moderate	strong
Behaviour			
RS for R-L skill	absent	moderate	strong



Percent left writers	34	8	1

0 - R=L skill

x - Threshold for left handedness when population incidence is 10 percent.

conditions for speech processing (arrived at by chance) plus the advantage of no over commitment to the LH. Another 25% is expected to develop all speech processing abilities together but in the R hemisphere and these would also not be anticipated to be at risk for phonological deficits. However the remaining 50% would be anticipated to develop some phonological processes in different cerebral hemispheres and would therefore be at risk for phonological processing deficits and/or other weaknesses associated with random lateralization of components of speech.

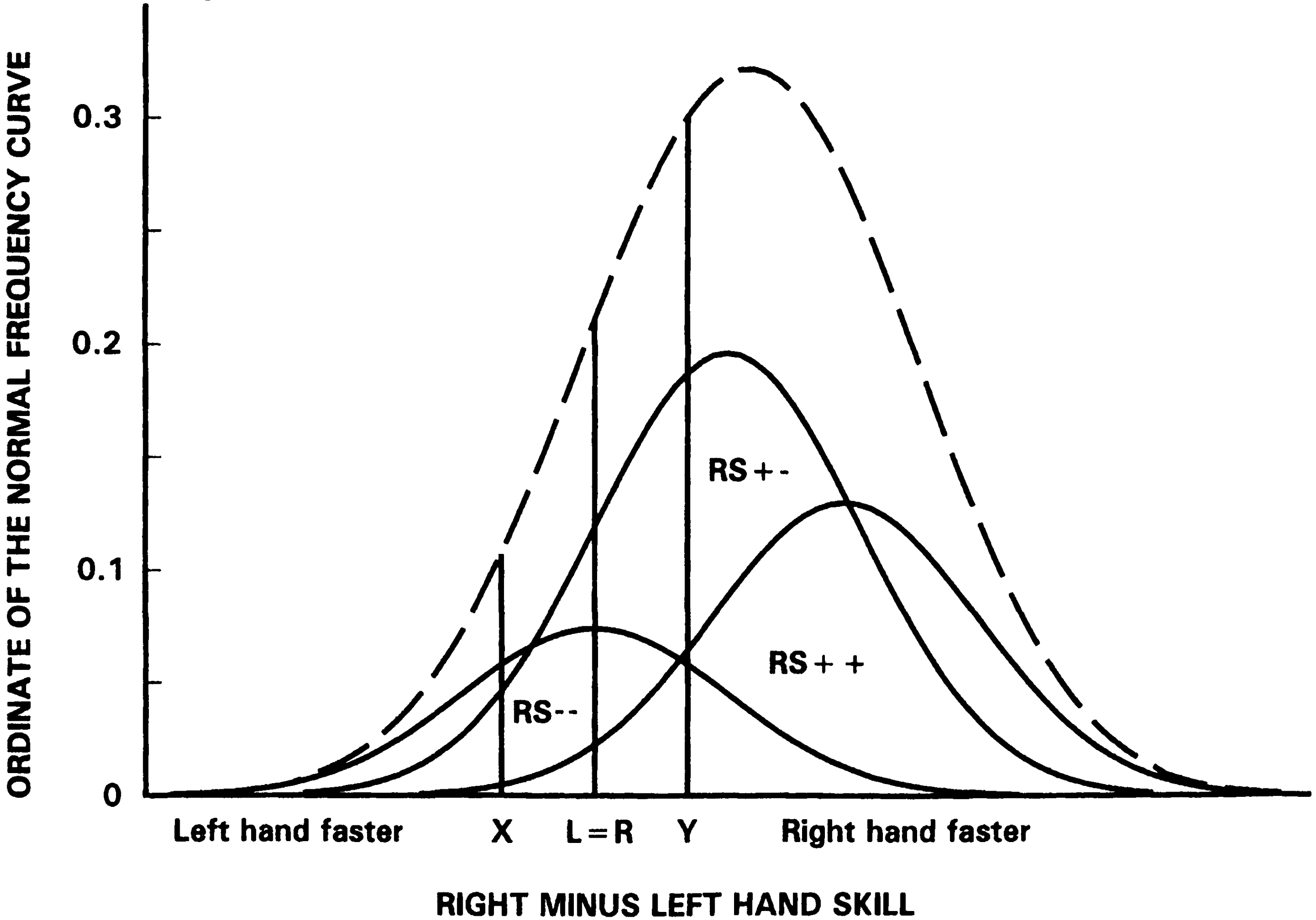
Returning to level three of figure 1.2, disadvantages for the RH associated with the rs+ gene are expected to be stronger in the rs++ genotype than in the rs+- genotype. Although at present it is unknown what these deficits are visuospatial processing is a strong possibility but empirical support is necessary for confirmation. There is an overall balance in the population, of advantages and disadvantages, for all genotypes with the (rs+-) heterozygote in the fortunate position of having neither problem associated with the two homozygotes (over commitment to the LH or risk to speech processing).

Level four explains the behavioural predictions that are made for each genotype. The primary influence on asymmetry is chance with all three genotypes expected to have chance distributions of R-L hand skill that vary in their degree of shift to dextrality. The rs-- distribution has no shift; the rs+- has a shift of approximately one standard deviation while the rs++ is shifted by approximately two standard deviations. The percentage of left-handers in each group will vary in different cultures and historical periods as due to differing social pressures and researcher's selection criteria. Fewer individuals are expected to be left handed in a strict social and/or cultural climate while more are likely to be left handed where there is less control. A population with approximately 10% left handers will be expected to have 34%, 8% and 1% left handers in the three genotypes (rs--, rs+- and rs++ respectively). These three genotypes are expected to overlap considerably (see figure 1.3) when examined along the continuum of R-L hand skill and genotype differences exist alongside the continuous background of chance. Annett has used the analogy of signal detection theory to demonstrate how the signal (specific effects due to the presence of the rs+ gene) is always accompanied by, and must be detected against, the background of noise (chance). The *random,* congenital not genetic, asymmetries of hand and brain that can happen in early human development were explained by another analogy (of a building, garment or model, which is designed to be symmetrical, but develops accidental asymmetries in its construction). The rs+ gene is a small but systematic influence that adds to these naturally arising random asymmetries. Anything, which slows development, is expected to obstruct expression of the rs+ gene so that the handedness distribution becomes closer to the distribution when the gene is absent (with a mean of approximately 0 as in the rs-- genotype). Annett has suggested that this explains sex differences, the effects of twinning (and the higher numbers of left-handers in premature (Ross, Lipper & Auld, 1992) and very low birth weight babies (O'Callaghan, Burn, Mohay, Rogers & Tudehope, 1993). Males are usually less mature than females at birth while twins tend to be smaller than singletons at birth and both males and twins are slightly more often left handed. Annett suggests that any mechanism, which disrupts the normal pattern of cerebral maturation, would leave the R-L asymmetry distribution closer to symmetry (around 0). Consequently the slower maturity of both males and twins is expected to result in slightly more left-handers. Cases of pathological left (and right) handedness are expected to occur but Annett warns that these are special cases and their hand preference is a separate issue which should be discussed independently of the majority of the population. She cautions that the fact that some left-handers are pathological in origin does not mean that all left-handedness is due to pathology (as in the theories of birth order or birth stress (Bakan, 1971, Bakan, Dibb and Reed, 1973) or abnormality (Coren, 1992).

In 1985 McManus suggested a theory of handedness that bears some similarities to the Annett RS Theory. However McManus proposed that a gene for dextrality or a gene for chance may be inherited. It is difficult to imagine why a gene for chance would survive in any population, as chance is eternally present without a genetic agent. Annett's theory, in contrast to McManus's, does not suggest a gene that directly influences handedness but one that, if present, directly influences the cerebral dominance, of speech processing, in the majority of individuals. Handedness becomes involved only as a side effect of the influence on cerebral dominance.

The RS theory predicts that three genotype distributions exist and they have considerable overlap between them (as can be seen from figure 1.3). This makes the theory difficult to test because firstly, the two homozygote distributions do not have mid-points at the

Figure 1.3

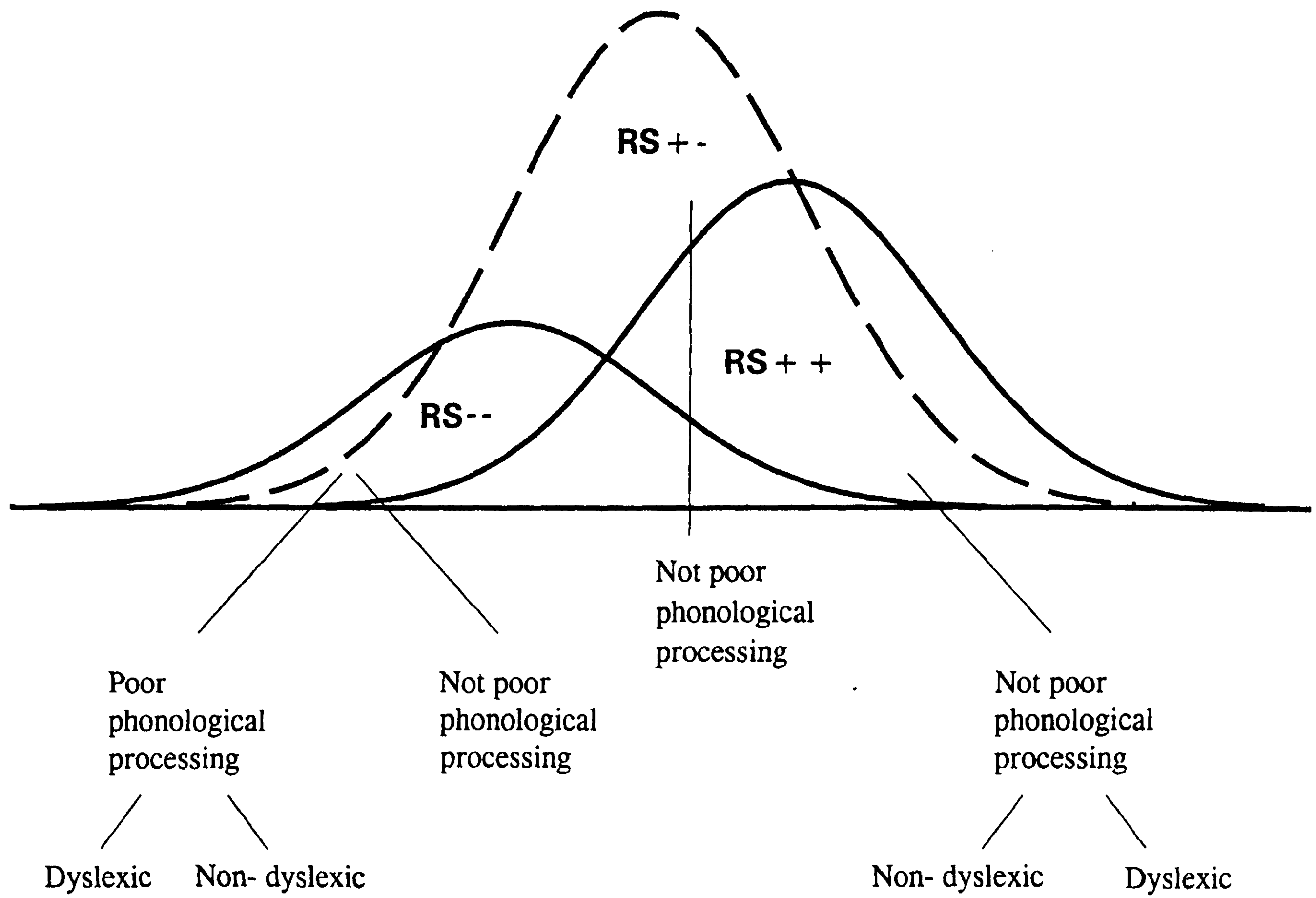


ORDINATE OF THE NORMAL FREQUENCY CURVE
0.3
0.2
0.1
0
RS+-
RS++
RS--
Left hand faster
X
L=R
Y
Right hand faster
RIGHT MINUS LEFT HAND SKILL

extremes of the overall handedness distribution. Secondly, the cognitive deficits for which homozygotes are *at risk* are only found in some, not all, individuals in that genotype. However these deficits are often described as occurring at each end of the combined distribution. This can result in misunderstanding, as individuals with extreme R-L asymmetries for handedness are not necessarily expected to demonstrate these deficits. The large overlap, of three distributions, combined with a risk for *any* individual in each homozygote ensures that when planning an analysis care must be taken about which variables are treated as independent and which as dependent. Two methods of analysis are possible, either to classify for handedness and then test for cognitive deficit or to classify for cognitive deficit and then test for handedness. If handedness is used to select groups only a small proportion of each group would be expected to demonstrate a deficit. Consequently the power of the analysis would be reduced and results could not be viewed with confidence. If this method, of arguing from laterality to difficulties in the population, is used then very large and representative samples are necessary. The second method of analysis is more powerful. Independent cognitive measures are used to select groups that are expected to contain large numbers of rs-- and rs++ genotypes. This method should demonstrate hand skill differences more clearly due to the different shifts of chance distribution for each genotype. Although large samples can be classified for handedness, the greater power of classifying for cognitive (independent) variables before testing for hand skill and hand preference (dependent variables) has led to the latter method of analysis being used predominantly in this thesis.

Several predictions of the RS Theory have been tested and a number of the findings are relevant to dyslexia. Support for a risk of dyslexia in the rs-- genotype was demonstrated by Annett & Kilshaw (1984) when they found twice as many left writers in a dyslexic clinic sample than in controls. A sub-group of dyslexics however were found to be strongly dextral. Previously a decline in spatial ability had been found along the continuum of L-R hand skill in both left and right-handers in samples of children and students (Annett, 1992c; 1994). A risk for literacy in normal children was supported by Annett & Manning (1990) who found, in both sexes, that children were poorer readers at both extremes of the hand skill distribution than those in the middle. Annett (1991a, 1992a) also found evidence, in samples of children and undergraduates, that those with poor phonology are less biased to the right hand for hand skill. Poor literacy, but different

Figure 1.4 Risks for Different Genotypes



types of dyslexia, at both extremes of the laterality continuum has also been supported in the present sample (Annett, Eglinton & Smythe, 1996). A whole age cohort of 9-10 year old schoolchildren in 9 schools (approximately 500 children) was investigated using tests of literacy, phonology and hand skill. This is part of the present research to be examined below.

The two major predictions of the RS Theory which concern this thesis are that (a) poor phonology is associated with reduced dextrality and (b) that at least two types of dyslexia exist, with groups of affected individuals differing in handedness from each other and the rest of the population (see figure 1.4). Two relevant issues are that (a) deficits in phonology have been found in individuals who are not dyslexic and (b) not all dyslexics have deficits in phonology. Before exploring these further, several major issues concerning dyslexia must be addressed.

Dyslexia.

Brain damaged, adult subjects who were poor at reading nonwords in comparison with real words have frequently been described (e.g. Beauvois and Derouesne, 1979; Shallice and Warrington, 1980; Patterson, 1982; Funnell, 1983). This pattern of reading problem is frequently referred to as acquired phonological dyslexia. In contrast others have described subjects who have no problem with reading regular and nonwords but have great difficulty with irregular words (e.g. Behrmann & Bubb, 1992; Bub, Cancelliere & Kertesz, 1985; Coltheart et al., 1983; Marshall & Newcombe, 1973; Patterson and Marshall & Coltheart, 1985). This syndrome is termed acquired surface dyslexia.

Similar patterns of difficulty to those found in acquired dyslexics have also been described in children with no apparent evidence of neurological abnormalities (e.g. Holmes, 1973; Coltheart, Masterson, Byng, Prior and Riddoch, 1983; Job, Sartori, Masterton & Coltheart, 1984) and these children are often called developmental dyslexics. It has been known for many years that some children find great difficulty in learning to read and spell although they have normal intelligence and sufficient opportunities to learn. Kerr & Morgan suggested, in 1896, that there could be a developmental form of dyslexia; a proposal that was worked on by Hinshelwood (1917) and Orton (1937) and has now become a major area of research. However several issues, briefly outlined below, that concern terminology, selection, controls, genetics and subtypes of developmental dyslexia still remain controversial.

Controversial Issues concerning Developmental Dyslexia.

Various terminologies have been used to describe the condition (e.g. "congenital word blindness" Hinshelwood, 1917; "strephosymbolia" Orton, 1925 and "specific dyslexia" Hallgren, 1950). Current reports generally prefer "specific dyslexia" and "developmental dyslexia" but problems and disputes about definition continue.

Dyslexics have traditionally been recognized when reading ability is poor although IQ is above a certain level but this method can lead to the exclusion of children with high IQs but only mediocre reading ability. Some researchers have tried to solve this by using regression to select children whose reading is below the level predicted by their IQ (e.g. Rutter, Tizard & Whitmore, 1970, Yule, 1973). Bishop (1990b) has suggested that these two approaches select different subsets of children.

Further difficulties involve the question of the measurement of IQ. Because dyslexics are identified by their poor reading ability in relation to IQ the type of IQ test that is used for measurement is important. Reading ability is more strongly correlated with verbal than non-verbal ability so children's reading skills may be poor when compared with their non-verbal IQ but not when compared with their verbal IQ (Bishop and Butterworth, 1980). This thesis is primarily concerned with phonological processing so the controversies about I.Q. have not been directly addressed, although they have been borne in mind and were considered in the selection of "dyslexics" in the Wellcome sample.

Little evidence for a single syndrome of developmental dyslexia was found by Rutter (1969, Rutter, Tizard & Whitmore, 1970) when large variations in neurological abnormality were identified amongst poor readers. Consequently, Rutter proposed that the term "specific reading retardation" should be used, instead of "developmental dyslexia", to describe children whose IQ is normal but reading is poor for their age despite adequate opportunity to learn. This was to contrast with "backward readers" whose reading is poor but commensurate with their IQ. However, although this suggestion has received support the shorter, more convenient, term still dominates the literature and for this reason it will be used throughout the present thesis.

The measure of reading ability that is used to select dyslexics can also influence their selection. If reading comprehension relative to IQ is used as a definition, instead of reading accuracy, many more children will be identified as dyslexics (Bishop and Adams, 1990). However this thesis is concerned primarily with investigating phonological skills so measures of comprehension have not been included. A further complication arises because the degree of normal reading lag has been found to vary with age so that 22% of 12 year olds but only 3% of 8 year olds will have a reading age of 24 months below age level (Elliott et al., 1978). Bishop (1990) has suggested that this problem can be solved if reading impairment is defined in terms of standard scores.

One approach to the investigation of dyslexia attempts to identify deficits that are found in dyslexics, but not normal readers. The performance of groups of dyslexics and normal readers of the same age and intelligence (CA controls) has been compared on tests of cognitive processing. By definition the dyslexics in these studies are poorer readers than the CA controls. This method of investigation has been criticized and Morrison and Manis (1982) suggested that it cannot be known, when a cognitive deficit is found in dyslexics but not CA controls, whether the deficit causes their reading problems or results from them. An alternative method compares groups of dyslexics with controls who are typically much younger but have the same reading ability on standardized tests of reading (RA controls). The expectation is that the dyslexics and the RA controls are equally familiar and proficient with printed words and their experience with written language is approximately equal. Qualitative differences are now expected to explain the causes of dyslexia. However there are still problems with this as the dyslexics are chronologically older than the RA controls so any differences could result from cognitive immaturity and could simply improve with age. Ideally investigations should include both CA controls and RA controls.

Behaviour genetic analyses of reading disability have demonstrated a high level of heritability for reading skills (DeFries, 1991). Evidence has been found, by several studies, that some genetic component is involved in specific reading difficulties when poor phonological skills are involved. Olson, Wise, Conners, Rack & Fulker (1989) studied identical twins where one twin had reading difficulties. Their results suggested that if the first child had phonological problems (indicated by poor nonword reading) the likelihood of the other twin also having a reading difficulty was high. However if the first child had problems with whole word reading then the other twin was no more likely to have a reading problem than an unrelated child.

Olson et al. found that word specific knowledge in reading was mainly influenced by environmental factors suggesting persistent practice and exposure to print as being most important. They also showed that nonword reading ability and ability in a phoneme segmentation task were strongly correlated ($r= 0.50$, controlling for age). Snowling suggests that this indicates that deficits in nonword reading may depend on underlying deficits in language skills. Interestingly evidence has also been found for a genetic basis for specific language impairment (S.L.I., see Gopnik, 1992, for a review). Individuals with S.L.I. are not dyslexic. They do however have a near normal I.Q. on tests of non-verbal performance combined with slow and difficult speech, with many grammatical errors (especially for pronouns and inflections). A study of the heritability of the disorder in one British family suggests that a single dominant gene is involved. Several researchers have expressed the view that S.L.I. and developmental dyslexia could lie on a continuum (Beaton, 1997; Gallagher, Frith & Snowling, 2000). Gallagher, Frith & Snowling (2000) retrospectively analysed the preschool language development of literacy-delayed children and found them to be subject to a mild delay in all aspects of spoken language

Other studies have suggested that the transmission of reading disability may be consistent with a major gene influence (Gilger, Pennington & DeFries, 1991) and recent segregation analysis of reading performance in normal readers suggested a major gene which affects the tendency towards reading problems (Gilger, Borecki, DeFries & Pennington, 1994). Reynolds, Hewitt, Erickson, Silberg, Rutter, Simonoff, Meyer, & Eaves (1996) reviewed the literature and presented evidence from a large population based sample of twins. They found that 69% of variation in oral reading performance was heritable in both boys and girls while only 13% was due to shared environmental effects. The relative importance of genetic and environmental influences was found to be equal for males and females but males showed greater phenotypic variability than females.

Rutter & Yule (1975) found that 77% of 86 specifically retarded readers were boys in comparison to 54% of 79 generally backward readers. This sex ratio of 3.3 males to 1 female amongst children with specific reading retardation is similar to figures reported for other developmental language difficulties (Bishop 1990b).

It has been suggested that there are problems with defining the nature of developmental dyslexia because it exists in more than one form (e.g. Boder, 1973; Mattis, 1978). Many researchers have used the existence of two types of acquired dyslexia (Marshall & Newcombe, 1973) as indicating the existence of two types of developmental dyslexia. Sub-classification of dyslexics, however, has led to disagreement about how divisions should be made (Satz, Morris and Fletcher, 1985) and how the reading errors of poor readers should be used to describe separate syndromes (Bryant and Impey, 1986; Baddeley et al., 1988).

Boder identified three groups amongst 107 poor readers and spellers. ("Dysphonetics" who made mostly phonetic errors, "dyseidetics" who made many visual errors and mixed readers who made a combination of the other two types of error.) She identified patterns, within the children's reading and spelling performance, from a study of the errors poor readers and spellers made. Further evidence for types came from Mitterer (1982) who gave a series of tests to backward readers to measure their dependence upon phonological and visual codes. Some children were found to read phonologically (finding irregular words difficult) while others read visually. The latter had problems with words composed of alternating upper and lower case letters (which appeared visually different). The authors claimed that these differences *only* existed in backward readers but this was not demonstrated as no reading age controls were used. However differences were found in backward readers although we cannot tell from this study whether they exist in normal readers. Frith (1979) also discussed the processing of words 'by eye' and 'by ear' and Baron (1979) suggested that normal readers could be divided into two types. She identified "Pheonician" readers, who depend heavily on a phonological (speech sound) code when reading and writing, and "Chinese" readers. The latter rely strongly on visual memory, recognizing words as patterns and remembering these patterns when they write.

Many single case studies of dyslexics have revealed heterogeneity amongst dyslexic readers. Two patterns of reading performance have been suggested where one involves an avoidance of phonological strategies (as found in dysphonetic dyslexia) and the other involves the use of phonological strategies (as in dyseidetic dyslexia). Children with the first pattern of reading performance have been called "developmental phonological dyslexics" and their reading resembles that of adults who have lost the ability to read unfamiliar words. They usually have difficulties with grammatical endings (e.g. 'ing', 'ly' and 'ed') and can have trouble with function words (e.g. 'of', 'for' and 'because') but can read familiar words and do not make semantic errors when reading aloud. Temple & Marshall (1983) described H.M. a 17 yr old female with a reading age of 10 yrs. They suggested that she had a phonological problem, as she could not read nonsense words or long regular words (eg "herpetology") and appeared to rely heavily on visual processing when reading. Many cases of developmental phonological dyslexia have been reported (e.g. Temple and Marshall, 1983; Temple, 1984; Seymour and McGregor, 1984; Snowling, Stackhouse & Rack, 1986; Campbell & Butterworth, 1985; Funnell & Davison, 1989; Hulme & Snowling, 1992; Holmes & Standish, 1996; Hanley & Gard, 1995; Castles & Coltheart, 1993).

In contrast Coltheart, Masterson, Bing, Prior & Riddoch (1983) described another 17 yr old female (reading age 10yrs) who displayed the opposite pattern of symptoms and resembled adult surface dyslexics. She could read regular words more easily than irregular words and made frequent "regularization errors". She also made stress errors (putting stress on the wrong syllable) and sometimes produced completely new words. Coltheart et al. suggested that she had difficulty with visual or orthographic strategies and could only read by decoding grapheme-phoneme correspondences. Several cases of developmental surface dyslexia have also been described in the literature (e.g. Holmes, 1973; Coltheart et al., 1983; Goulandris & Snowling, 1991; Seymour, 1986, 1990; Hanley, Hastie & Kay, 1992; Seymour & Evans, 1993; Broom & Doctor, 1995; Hanley & Gard, 1995).

Further evidence for "types of dyslexia" has also been reported by Castles and Coltheart (1993) who found double dissociations between similar patterns of disability in a group of dyslexic boys. Some displayed a pattern of reading problems that is widely thought to be characteristic of "phonological dyslexics". They were weak in sub-lexical skills, and so had problems with reading nonwords, but had relatively good visual memories (for reading real words with irregular spellings). In contrast other children had relatively good sub-lexical (G-P-C) skills but had difficulties with the visual processing of irregular words (e.g. "debt") as has been found in surface dyslexics (Patterson, Marshall & Coltheart, 1985). Using similar methods Manis, Seidenberg, Doi, McBride-Chang and Petersen (1996) also identified two groups who fit the same profiles that are often referred to as "surface" and "phonological" dyslexia. Castles and Coltheart suggest that possibly one in three children with reading disorders can be expected to have a particular problem with one reading procedure in the absence of any difficulty with the other while many more children are expected to have difficulties with both. It has been proposed that these types of dyslexia might be due to subtle difficulties with the spoken form of language, in the case of phonological dyslexics and with a deficit in visual memory, in the case of surface dyslexics (Ellis, 1985).

However Goswami and Bryant (1991) suggested that longitudinal work is necessary as the two "types" of children could merely be at different levels of development. Some researchers have taken an opposing view suggesting that most impairments in developmental dyslexia lie upon a continuum rather than falling into categories (Seymour, 1987a; 1990 and Wilding, 1989; 1990). Wilding (1990), in a similar argument to Snowling, (1992), suggested that in his sample of 6 subjects with reading problems, all (with one possible exception) had a phonological processing deficit. He proposed that what varied was the coping strategies that they adopted to counteract this difficulty when attempting to convert print to sound.

Snowling (1983, 1992) has recommended that the best comparison to make when investigating what has gone wrong is not between developmental and acquired dyslexics but between developmental dyslexics and reading age matched controls. Bryant & Impey (1986) used this type of comparison when they found that "normal" children made the same type of reading error as dyslexics. Only nonword reading, which relies heavily on phonological skill, was found to distinguish dyslexics from normal children. Baddeley, Logie & Ellis (1988) also found that developmental dyslexics and normal children make the same mistakes when they compared dyslexics, reading age controls and chronological age controls who read regular words, irregular words and nonsense words.

Differences have also been described in the way children spell ("Pheonicians" and "Chinese" types) (Baron and Trieman, 1980; Baron, 1980; Trieman, 1984). Temple (1986) described two children who were very poor readers and spellers and at 10 yrs old had a spelling age of 7 years. The girl did not have difficulty with reading regular words or nonwords but was poor at reading irregular words. In contrast the boy read irregular words as well as regular words but was poor at reading nonwords. Their spellings of 160 words were compared with those of normal 7 yr olds and it was found that the girl, but not the boy, spelled in a similar way to the normal children. The boy appeared to be insensitive to rhyme; he couldn't produce them and made many mistakes when trying. It was suggested that he was insensitive to phonological segments.

Overall considerable differences have been found amongst developmental dyslexics in their approach to reading (Olson, Kliegl, Davidson & Foltz, 1985; Seymour, 1986) but the question of sub-types is still controversial (Rack, Snowling & Olson, 1992; Wilding, 1989).

Atypical Cerebral Organization associated with Dyslexia.

It has been suggested that children with developmental dyslexia may have a neurological basis for their difficulties with reading and/or spelling. Evidence for atypical cerebral lateralization in dyslexia has been found in studies that have used dichotic listening. This relatively simple non-invasive task can be used for examining hemisphere asymmetry in normal samples but it cannot be relied upon to diagnose the cerebral speech hemisphere of individuals (Kimura, 1961, 1967; Bryden, 1982). An association can be demonstrated but dichotic listening is not diagnostic. Bryden reviewed the literature in 1988 finding 14 studies with no evidence for a difference between disabled readers and controls, 30 where poor readers were less lateralized than controls and 7 where poor readers were more lateralized. Dyslexics tend to make more errors than controls on verbal dichotic tests but they usually demonstrate a reduced right ear advantage, which could imply more bilateral language processing. Bryden did not come to this conclusion but proposed that comparisons should be made between dyslexic children and reading age controls. However, Bishop (1990b) has warned that these studies often exclude non-right handers as investigations using dichotic listening to assess cerebral lateralization in normal subjects exclude individuals who are likely to be atypical. Excluding those who are likely to have atypical lateralization from studies that investigate the occurrence of an atypical pattern will bias the studies against finding an effect. These studies remain inconclusive but further evidence indicating atypical patterns of cerebral lateralization in dyslexics has been found in morphological studies.

Cerebral differences in dyslexics have been investigated both in post-mortem studies and more recently using modern physiological measurements. Functional magnetic resonance imaging (fMRI) scans, which are considered non-invasive, have been used to investigate patterns of cerebral activation in children with dyslexia. Anomalies have been reported of small corpus callosi, symmetrical or missing gyri in the auditory cortex and abnormalities of the angular gyrus. However a complex and sometimes conflicting pattern of results has been produced. Different studies have used varying definitions of dyslexia for sample selection and differing systems of measurement (e.g. linear or area) to determine the size of assorted cerebral regions. This makes the direct comparison of many studies difficult.

Several studies have found evidence that the normal pattern of morphological brain asymmetry is absent in dyslexics. Hynd et al. (1991) reviewed computerized tomography (CT) and MRI studies examining anomalies in brain morphology that appeared to be associated with neurolinguistic functioning. Earlier research suggested that dyslexics showed variations in specific brain regions (i.e. reversed or symmetrical plana temporale, smaller bilateral insular length and symmetrical frontal regions).

Post-mortem studies have found leftward asymmetry of the planum temporale in most normal subjects (e.g. Geschwind and Levitsky, 1968; Witelson and Pallie, 1973; Galaburda et al. 1987; Chi et al. 1977; Aboitiz et al., 1992). However several post mortem studies of dyslexics have found an atypical pattern of symmetrical plana (e.g. Galaburda and Kemper, 1978; Galaburda et al., 1985; Humphreys et al., 1990). Many, but not all, modern neuroimaging studies have supported this finding (e.g. Rumsey et al., 1986; Larsen et al., 1990; Hynd et al., 1990; Kushch et al., 1993). Some neuroimaging studies (e.g. Kertesz et al., 1990; Habib et al. 1995; Foundas et al., 1995) have also found larger or longer plana in right-handers than in left-handers despite differences in subjects, measurement and algorithms.

In 1997 Beaton extensively reviewed the evidence for a relationship of both planum temorale asymmetry and corpus callosum morphology with handedness, gender and dyslexia. He made the point that even the apparently robust findings, which have been found by at least some MRI studies, could simply be an artefact of measurement. An apparently strong finding of larger planum temporale on the left side has been shown by some MRI studies. However when Loftus, Tramo, Thomas, Green, Nordgren and Gazzaniga (1993) compared the use of two algorithms when measuring the planum they found contrasting results. Taking into account the folds and curves of cortical surface across adjacent coronal sections found no left-right asymmetry but not taking these into account produced a significant left-right asymmetry. In addition Steinmetz et al. (1990) using both post-mortem and MRI measures demonstrated a significant leftward asymmetry of exposed planum but a rightward asymmetry of total surface of cortex that was buried posteriorly to the planum. Consequently the combined surface area buried in the whole posterior Sylvian fissure caudal to the first transverse gyrus had no asymmetry (also see Witelson and Kigar, 1992; Rubens et al., 1976). (See Glickson and Myslobodsky (1993) for a discussion of other misleading inferences.)

Beaton concluded that the uncertainty concerning the significance of asymmetry of the planum temporale and its possible association with handedness needs to be borne in mind while explaining the importance of findings of deviations from the normal pattern (e.g. in dyslexia). This is certainly true but there is undoubtedly evidence that cerebral asymmetry has been found to be reduced or absent in some dyslexics (e.g. Flynn and Boder, 1991; Larsen, Hoien, Lundberg and Odegard, 1990; Cohen, Hynd and Hugdahl, 1992) while increased hemisphere asymmetry has been demonstrated in others (e.g. Rumsey, Berman, Denckla, Hamburger, Kuesi and Weinberger, 1987 who used strongly right handed participants). Despite reservations about the use, in various studies, of different measurements, algorithms and definitions of dyslexia, this pattern of cerebral asymmetry is consistent with predictions of the RS Theory.

Some physiological studies of normal readers have also found evidence indicating the existence of different pathways of cerebral activation for specific tasks associated with literacy. Petersen et al. (1988), in a series of PET scan studies, identified areas of the brain concerned with the processes of visual and auditory word perception and areas involved with the formation and articulation of speech. Generating a response to a noun (whether heard or seen) was found to involve contributions from many areas organized into unique networks for each mental process. Processes included word perception, speech production and semantic access. Two LH areas, one anterior and one posterior, became active during studies of rhyming visual and auditory words. The posterior area seemed more related to word sound and the anterior more related to word articulation. Similar areas were also involved in working memory for verbal material. They found that several adjacent areas in the left posterior temporal lobe were involved in processing words. One area appeared to be concerned with the processing of auditorily presented words and the other with visually presented words. Interestingly the left occipital lobe contained areas along the midline that processed printed English words or lawful nonwords, but not consonant strings. Petersen et al. argued that this ability cannot develop until a child learns to read, usually around 6 years of age, with the brain continuing to change in organization as new skills are acquired.

Different pathways of cerebral activation were also found by Raichle, Fiez, Videen, Macleod, Pardo, Fox, and Petersen (1994) depending upon whether a task of verb generation was practised or unpractised. This led them to conclude that two pathways were available for generation but the choice of route could depend upon how much the task had become automatic through learning. One pathway included the anterior cingulate cortex (with Broca's area) the left temporal cortex (including Wernicke's area) and the right cerebellum and the other included the buried insular cortex in both hemispheres.

In an important study Pugh, Shaywitz, Shaywitz, Shankweiler, Katz, Fletcher, Skudlarski, Fulbright, Constable, Bronen, Lacadie & Gore (1997) related processes in word identification to brain physiology. Activation was demonstrated in different cortical areas for different processes. The extrastriate region was activated for orthographic (sight based) processes; the inferior frontal gyrus for phonological (speech sound based) processes and the superior temporal gyrus were activated when the two were integrated.

Models of Reading and Spelling

This evidence for two different pathways of cerebral activation for the generation of practised and unpractised verbs can be interpreted as support for the existence of two different routes for reading. One route would be expected to be learned and involve access to a lexicon while the other would be expected to be sub-lexical depending on decoding unfamiliar words. Further support for separate routes comes from the evidence for activation of different cortical areas for different processes (orthographic and phonological) in word recognition. Various models of reading have been suggested and these fall broadly into the two categories of dual route and connectionist models, which are briefly described below.

The proposal of a dual route model (Coltheart et al., 1977; Coltheart, 1978), and a similar three-route model (Morton & Patterson, 1980), followed the discovery of different types of acquired dyslexia. The dual route model suggests that two separate pathways are available for skilled readers when they are converting text to speech. These are (1) a lexical or word specific route, which accesses internal units consisting of entire words, and (2) a sub-lexical route, which uses a system of rules for specific relationships between sub-word units of text and speech (i.e. graphemes and phonemes). In these models problems with either the word specific or the sub-lexical route are expected to result in specific difficulties with reading or spelling as outlined below.

The lexical route involves recognising an orthographic (visual) representation of a word and retrieving it's associated phonetic representation (sound). Normally this process can occur directly and immediately but entries will not exist, in the internal lexicon, for new words, which have not become familiar shapes. In contrast, the non-lexical route involves the graphemic representation (letters and/or groups of letters) of a word being transferred into the phonetic representation (sounds) in stages. Firstly the visual representation of the word is segmented and split into individual units of letters or combinations of letters. These are then transformed by grapheme-phoneme conversion (G-P-C) and mapped onto their corresponding phonemes (sounds). Finally the phonemes are restrung, blended and reassembled so that a code for pronunciation can be set up. No entries could exist in an internal lexicon for nonwords (strings of pronounceable letters, which are not real words e.g. "luf") as they are novel and can never have been seen before. Consequently, nonword reading and spelling are often used to test the efficiency of the non-lexical route. In these models words with irregular spellings (e.g. “draught”) cannot be processed by the non-lexical route as appropriate grapheme-phoneme correspondences do not exist for them and they can only be accessed by the direct lexical route.

Similar models for spelling also describe both a direct lexical route and an indirect sub-lexical route, which approximately reverse models of reading. However before the process can begin an acoustic pattern of sounds must first be decoded into a speech relevant phonetic pattern. The lexical route, for spelling, involves retrieving the orthographic (visual) representation of a word by association with its phonetic representation (speech sound). Normally this process can happen directly but some words have the same sounds but different meanings (e.g. see, sea). These homophones and their semantic representations (meanings) must be decided before correct orthographic representations can be accessed. Again no entries will exist in the internal lexicon for new words, which have not become familiar shapes. The sub-lexical indirect route for spelling involves the phonetic representation (sound) of a word being transferred into its graphemic representation (letters) in three stages. The first stage is segmentation when the word is split into it's individual units of sound (phonemes), then phoneme-grapheme conversion when the phonemes are mapped onto letters or combinations of letters and the final stage is restringing when the graphemes are reassembled to form a word. Again the non-lexical route in this model cannot process words with irregular spellings, as appropriate phoneme-grapheme correspondences do not exist for them.

Several researchers have proposed connectionist models as alternatives to dual route models (e.g. Patterson, Seidenberg & McClelland, 1989; Seidenberg & McClelland , 1989; Plaut, McClelland, Seidenberg & Patterson, 1996). Unlike dual route models, connectionist models of reading propose that 'rule-like' behaviour can be accomplished by systems that do not contain explicit representations of rules. The Seidenberg and McClelland model (1989) attempted to account for several aspects of lexical processing (i.e. the access to meaning and spelling from speech, and the access of spelling and pronunciation from meaning). It describes a system of complex automatic mappings that develop between the orthographic (visual) and phonological (sound) representations of words. These automatic mappings are interactive parallel processes within the lexicon and access to phonological information automatically follows recognition of a word. This access can be direct or indirect depending upon the time course of the decoding process.

High frequency words are quickly recognized but low frequency words take longer and this allows more time for phonological information to assemble. This could be because sub-lexical orthographic patterns (groups of letters which are often found together) or lexical items in a group of candidates (similar words) activate their phonological representations. This would mean that only the more slowly recognised lower frequency words would be processed phonologically (Seidenberg, 1985b).

In contrast to the dual route model this process is interactive and has no rules to specify regular spelling to sound correspondences of language. There is also no phonological lexicon in which pronunciations of words are stored. All words and nonwords are pronounced using the knowledge encoded by a single set of connections. The network model allows this to operate by one mechanism that uses weighted connections between the units. Phonological output is computed on a single forward pass through the network. Processing is accomplished by parallel systems rather than the serial systems of dual route theories.

There is considerable debate in the literature about the range and limitations of this approach (Pinker & Prince, 1988; Coltheart, Curtis, Atkins & Haller, 1993; Castles & Coltheart, 1996). Coltheart, Curtis, Atkins & Haller (1993) and Castles & Coltheart et al. (1996) assert that these models have not successfully simulated regularization errors and that this failure supports dual route theories. Regularization errors involve over-applying phonological rules and attempting to make irregular words conform to by them. Zorzi, Houghton & Butterworth (1998) have attempted to solve this problem by designing a two-tier network that extracts regularities in spelling-sound mapping from training data containing many exception words. They conclude that the organization of the reading system reflects the demands of the task and that different processes compute the pronunciation of nonwords and exception words. Recently Harm and Seidenberg (1999) have shown that errors of the kind made by "phonological" and "surface" type developmental dyslexics, which are usually attributed to impairments in distinct lexical and non-lexical processing "routes", can be derived from different types of damage to a connectionist model network.

Nevertheless it could be argued that the incapacity of a computer simulation to replicate one particular error when others are demonstrated does not necessarily mean that the whole model should be discarded, only that certain details have not yet been satisfactorily addressed. It seems likely that eventually one form of connectionist model will prove to be substantially accurate, but as yet they are not sufficiently developed to enable them to be as useful a tool, for prediction, as dual route models. However the clear division of dual route models into two separate routes for phonological and visual recognition makes them convenient for investigating deficits that cause problems with reading and spelling ability. Consequently dual route terminology will be used as a tool throughout this thesis but the topic will be returned to in the discussion chapter.

Part 2: Aspects of Phonological Processing and Literacy.

Poor readers and spellers have frequently been found to have deficits in phonological processing (Manis, Szeszulki, Holt & Graves, 1990; Seymour & McGregor, 1984; Snowling, Stackhouse & Rack, 1986; Temple & Marshall, 1983) but controversy surrounds the role of phonological processing in learning to read and spell.

Frith (1985) made the suggestion that reading develops in a series of three stages culminating in full literacy. These stages are sequential and move in an established order with each building upon the previous one. In Frith's view "classic" developmental dyslexia results from a child's inability to break through to the second stage, which depends upon phonological abilities, so that reading and spelling becomes arrested at the initial stage. Frith proposed that children in the first logographic stage remember words by features (e.g. initial letters or word length). Consequently they make visual reading errors (e.g. reading 'bad' for 'ball' or 'television' for 'telephone'). The child's only strategy to decode unfamiliar words, at this stage, is to rely on visual similarities to known words. Spelling is also basic and the child will only spell a few very familiar words, which are learned by rote (e.g. their name). In the next, alphabetic, stage the decoding of words begins and left to right mappings between letters and sounds must be mastered. At this stage a child who sees the letters h-a-t knows the corresponding sounds are /h/-/a/-/t/ and can then build up the word 'hat'. Awareness of the relationship between sounds and letters now lets the child spell a phonetic version of spoken words. Some phonemes correspond to more than one grapheme (e.g. /e/ corresponds to 'e', 'ea' and 'ee' etc.) and the correct grapheme must be chosen to spell any particular word. Consequently it takes time before a child can spell orthographically (i.e. choosing the correct letters for the sounds). Reading errors at this stage are often of irregular words where applying the logical rule leads to an incorrect pronunciation. The final orthographic stage is automatic but flexible and Frith suggests that both reading and spelling are now independent of sound with analogies being used for both. Words are analysed into orthographic units without phonological conversion. These units are internal representations of abstract strings of letters, which are independent of sound so that 'tion' is recognised as a final syllable without a need to pronounce it in reading or sound it out for spelling. In this way adult mechanisms are established.

Frith suggests that reading and spelling do not develop in parallel but that they take shape out of phase with each other. Consequently, a child can be in one phase for reading and a different one for spelling. She proposes that logographic skills emerge first in reading and alphabetic skills in spelling. A normal child therefore learns to use phoneme-grapheme conversion skills for writing first and then transfers them to reading.

"Classic" developmental dyslexia is explained by Frith as arising when a child cannot break through to the alphabetic stage and reading and spelling become arrested at the logographic phase. This allows the child to read and spell familiar words but they are prevented from processing unfamiliar words. This is the pattern of difficulties found in individual case studies with developmental phonological dyslexia. Frith has suggested that if the widely held hypothesis, that dyslexia results from a difficulty with the phonological analysis of speech sounds, is true then various possibilities exist for the affected brain functions. These possibilities would lead to specific cognitive deficits that in turn would lead to the core problems that are frequently demonstrated by dyslexics (naming, short-term memory and phoneme segmentation). She emphasises that these problems are not directly concerned with reading and writing, but learning to read and write in an alphabetic script depends on the ability to segment phonemes (Frith, 1992).

Evidence to support Frith's logographic stage was found by Seymour and Elder (1986) when they studied children's reading mistakes while in their first year of learning to read. The children produced reading errors, which were similar in length to target items (e.g. "children" instead of "policeman" with the comment "I know it's that one because it's long"). Words with noticeable features in common were also confused (e.g. "smaller" and "yellow"), as were those with shared consonant clusters ("stop" and "lost"). In addition semantic memory appeared to be implicated in young children's reading as some errors were semantic (e.g. "room" read as "house"). The children also found nouns, which are easily visualized, easier to read than verbs. The results were interpreted as indicating a sight vocabulary stored in a lexicon with connections to semantic memory and output phonology (where pronunciations of spoken words are held). Printed words with lexical representations are recognised automatically but visually similar words are often misread for one another and words with similar meanings are often confused.

In order to become an efficient reader a child must develop skills in both phonological and orthographic processing (Frith, 1985; Stuart, 1990; etc.). There seems little doubt of the importance of phonological processing in the acquisition of reading and spelling skills. However the question of its precise role in learning to read and spell remains controversial. Evidence has been found for individual differences in the *ratio* of sub-lexical, phonological coding to lexical, orthographic knowledge that they use when processing words (Baron, 1979; Castles, Holmes & Wong, 1996; Trieman, 1984). Individual differences have been found in the strategies which children use for reading and spelling (Baron & Trieman, 1980; Barron, 1980) "Phoenician" and "Chinese" readers and differences amongst normal readers (Bryant & Impey, 1986) have all been described earlier, in the discussion of dyslexia sub-types.

There are also reports in the literature of adults, with serious problems of phonological awareness and phonological memory, who have still managed to become adequately skilled readers (e.g. Campbell & Butterworth, 1985; Holmes & Standish, 1996). Campbell & Butterworth (1985) described a female psychology student who had poor phonological skills but was good at reading and at orthographic processing. Holmes & Standish (1996) described an 18-year-old student who also appeared to be using superior orthographic skills to compensate for her impaired phonological processing. This evidence indicates that relying on orthographic knowledge, to enable readers to compensate for weak phonological skills, can continue into adulthood. It appears that efficient reading skills can be developed even in the presence of defects in phonological awareness and phonological memory. Stothard, Snowling & Hulme (1996) have reported a similar case of a child with phonological problems who was normal in her reading and spelling abilities. Snowling proposed that phonological deficits constrain the development of literacy skills but other capacities can compensate for these restrictions. She suggested an interaction between the different skills, which an individual brings to the problem. Gallagher, Frith & Snowling (2000) suggest that the higher I.Q. characteristics of certain at-risk individuals act as a protective factor against early literacy difficulties although problems may occur at later stages. Snowling has proposed that at the same time as difficulties with phonological codes emerge, compensating strategies are acquired over and above them and these strategies then dictate individual differences in reading and spelling skill. Variation in the relative use of different processing skills has been found (e.g. Rack, 1985; Stanovitch & Siegal, 1994) and there is some evidence for the existence of individual differences in strategies associated with literacy (Shafrir & Siegal, 1994; Olson et al., 1985).

Snowling (1992) has proposed that problems with different phonological processes could hamper the formation of alphabetic sound-spelling rules. This important suggestion about the nature of phonological processing is of major relevance to subsequent analyses in this text. Snowling distinguished three types or aspects of phonological processing. Difficulties with auditory perception (input phonology) would be expected to slow the acquisition of correct letter-sound correspondence rules. Problems with phoneme segmentation would be expected to affect spelling. Difficulties with output phonology (compiling and encouraging an output code for pronunciation) could hinder phoneme combination or blending processes. Snowling described a group of dyslexics with varying phonological skills. They all had verbal memory deficits and could segment by syllable but had problems with rhyming tasks needing phoneme segmentation. TW (the most handicapped of the dyslexics and still in the logographic stage) alone had difficulties with auditory discrimination. Two more (JM and KF) had speech difficulties, which suggested problems with output phonology. Variation existed within the group but all had problems with phonological tasks and in this way were different from reading age-matched controls. Snowling argued that a deficit in phonological processes caused their reading and spelling development to be blocked at an early stage. Following this it seemed that the dyslexics who progressed had restricted development in phonological skills. These remained weak even though progress to the alphabetic stage was ultimately achieved. Snowling suggested the problem could be one of phoneme awareness, phoneme segmentation, input or output phonology. She proposed that difficulties occurring in these different phonological processes could be responsible for the individual differences found in reading and spelling performance in the apparently homogenous group of phonological dyslexics. They could be similar in that they have not gained enough alphabetic skill but different because their problems arise in different phonological processes or combinations of processes (Snowling, Stackhouse & Rack, 1986).

Evidence for a shift from neurobiological to cultural regulation in phonological processing has been found in normal readers. Leonard et al. (1996) used MRI to explore phonemic awareness (defined as the ability to abstract and auditorily manipulate symbols) in 40 normal children (age 5-12 yrs.). Measurements were taken of indicators of overall brain size and the horizontal and vertical banks of the planum. In young children (5-9 yrs.) anatomical asymmetry of the auditory cortex predicted phonemic awareness but in older children the relationship disappeared. The authors suggested that children with different patterns of cognitive strengths and weaknesses could have differing spatio-temporal patterns of cortical development. The loss of association could be seen as evidence of a process of compensation for specific deficits in otherwise able children.

There has been considerable debate in the literature about the character of the connection between an awareness of sounds in spoken English and success in learning to read (Bradley & Bryant, 1983; Lundberg et al; 1988). Much controversy has concerned the relationship between phonological awareness (an awareness of the sound structure of language (Wagner and Torgesen, 1987) and literacy. The debate has centred on whether phonological awareness predates literacy, develops as a result of literacy or has a reciprocal relationship with literacy. Different aspects of phonological awareness have been proposed (Ehri & Wilce, 1987) and Morais, Alegria & Content (1987) have suggested three levels of phonological awareness. Morais et al. propose that the first two levels precede and contribute to literacy while the third only develops with the experience of alphabetic orthography. Wide support exists for the view that an awareness of the rhyming relationships between words precedes reading while an awareness of phonemes is at least partially a consequence of learning to read (Goswami & Bryant, 1991; Morais,1991). Bradley & Bryant (1983) used the ability of young children to identify a non-rhyming word, spoken amongst a list of rhyming words, to judge their sensitivity to rhyme. Four and five year old pre-readers could perform this task satisfactorily and the authors found it to be highly predictive of later ability in reading and spelling. This has resulted in rhyme judgements being generally accepted in the literature as measures of phonological awareness and they are used as such in several of the following analyses.

Phoneme segmentation (and deletion) involves splitting and manipulating the single speech segments (phonemes) in a word or nonword. The sequence of sounds that make up a word (i.e. "butterfly") can be divided into syllables (i.e. "but", "er" and "fly"). These syllables can be further sub-divided into single speech segments (phonemes) so that the syllable "but" becomes "b", "u" and "t". Children cannot usually divide a word into its syllables until around 4 years of age or divide it into phonemes until about 5 or 6 years. It has been suggested that this is an important pre-reading skill (Liberman et Al, 1977) that is a good predictor of later reading ability. Muter, Hulme, Snowling & Taylor (1997), in a recent longitudinal study of 38 children, found that skill in phoneme segmentation, not rhyme, predicted reading ability in beginning readers. Rhyming was not found to predict reading until the second year of instruction. There is evidence that both young children (Bruce, 1964; Liberman, Shankweiler, Fischer & Carter, 1974) and illiterate adults (Morais, Carey, Alegria & Bertelson, 1979) experience problems with phoneme segmentation tasks. There seems little doubt that an awareness of rhyme and the ability to segment phonemes are both important for reading skill so tasks involving both are used later in this thesis.

Trieman (1987) suggested that each syllable in English can be sub-divided into the intra-syllabic levels of onset and rime. The onset consists of a single consonant or a cluster of consonants whereas the rime contains the vowel plus concluding consonants (so that the word "bread" has an onset of "br" and a rime of "ead"). Difficulties in deleting onsets, which are consonant clusters, could indicate that a child has not reached a full phonemic representation of speech. In their review Goswami & Bryant (1991) concluded that young children who are adequate readers first develop an awareness of onset and rime and that this is causally related to their ability in reading. They suggested that awareness of different levels of analysis develop at different rates. An awareness of phonemes develops as a result of learning to read and this awareness begins by being most relevant to spelling and only later is used in reading.

Interest in anomalies in the auditory cortex of dyslexics increased following Tallal's (1980) findings that children with specific language impairment lack the usual left hemisphere specialization for processing rapid auditory changes. She showed that this inability to perceive rapid changes strongly predicts a difficulty with reading nonwords (an accepted criterion of phonological dyslexia). It is possible that there exists a sub-group of dyslexics with a primary auditory processing defect caused by anomalous development of auditory regions. One explanation suggests that the RH also performs crucial language skills early in development, perhaps by processing intonation and prosody (e.g. stress). Congenital or early developmental anomalies in the RH may push this function into the LH, with the result that LH systems are 'crowded' and cannot function normally.

A problem with processing basic sensory information, which enters the nervous system in rapid succession, is a candidate for causing problems with higher levels of speech processing. It has been suggested that problems here lead to difficulties with the normal development of language and reading (Tallal, Miller & Fitch, 1995; Stein et al., 1995). These researchers have proposed that normal auditory perception is necessary for the development of adequate reading skills and evidence is growing for low level deficits in visual and auditory perception in dyslexics (Stein, 1995; Galaburda & Livingstone, 1995).

Epidemiological surveys have found unexplained developmental speech or language defects in 3-10% of pre-school children with no evidence of hearing impairments, general mental retardation or neurological disorders i.e. seizures or acquired brain lesions (Beitchman, Nair & Patel, 1986). Mixed results have often been found in studies of literacy skills in children with speech impairments but when Bird, Bishop & Freeman (1995) investigated the link between expressive phonological impairments, phonological awareness and literacy they found that children with expressive phonological impairments scored well below matched controls on all tests of literacy irrespective of whether they had other language problems. Many knew letter sounds but were poor at reading and writing nonwords and real words. The authors suggested that both the speech impairment and the literacy problems stem from a failure to analyse syllables into smaller phonological units.

Separate Phonological Processes.

The suggestion that there are difficulties in specific areas of phonological processing implies that these processes could rely on separate systems. Nearey (1997) discusses theoretical and empirical arguments in favour of viewing speech production and perception as two distinct but co-operative systems. This section discusses three candidates for separate phonological systems and their relationships with literacy.

<u>Speech Perception.</u>

There is currently much debate in the literature as to whether speech perception is linguistic or acoustic in nature. Ohala (1996) reviewed three types of evidence and concluded that acoustic properties have largely driven the selection of sounds found in speech production. Fitch, Miller & Tallal (1997) reviewed research, on the mechanisms which process human speech in the brain. They concluded that speech processing could be separated into the different roles of complex acoustic processing and linguistic processing. Despite the controversy about the nature of speech perception individual differences have been identified, in normal subjects, in both auditory and phonological processing. Canevet, Marchioni (1994) found individual differences in auditory perception. They measured the auditory performance of 107 normally hearing listeners (ages 14 - 50 yrs) to estimate the distribution of perceptual abilities. The resulting model represented the main features of auditory perception by independent factors and each individual had a different 'psychoacoustic profile'.

Individual differences in speech perception associated with differences in cerebral morphology have also been found in 5 normal subjects (Binder et al., 1994). Investigating a phoneme discrimination task they found large variations between subjects in the location of signal changes associated with speech syllables (range 0.17 to 2.5 Hz). MRI scans during the task showed bilateral superior temporal lobe signals that increased together with stimulus presentation rate and task performance. Significantly more widespread signal changes were associated with speech stimuli than with noise and there was large inter-subject variability in the location of signal changes. The results emphasized the role of the superior temporal gyrus in the perception of acoustic-phonetic features of speech.

Several studies have found associations, in children, between speech perception and phonological awareness (Hurford, 1991; Flege, Walley and Randazza, 1992; Eisen, Fowler & Brady, 1995; McBride-Chang, 1995a, Manis et al., 1997). Coming at the beginning of the phonological process individual differences in perception could cause problems at a later stage. Possibly these problems could increase as the system progresses or they could be minimized due to compensation with other abilities. However, it seems possible that deficits in perception could be at least partially involved in reading difficulties.

When work on this thesis began there were relatively few studies examining the possibility that dyslexic children could experience problems with speech perception. Existing studies were often contradictory and inconclusive with some finding differences between dyslexics and normal readers (Brandt & Rosen, 1980; Godfrey et al., 1981) but others failing to do so (Snowling, Goulandris, Bowlby & Howell, 1986). Methodological differences appear to have contributed to these conflicting results. Ceiling effects, different assessment procedures and stimuli of varying difficulty (phonemes or syllables) could all be responsible for the inconsistencies. However recently evidence has grown for the existence, in some dyslexics, of a deficit in the perception of speech sounds which could cause their internal representations of phonemes to be inadequate. These incorrect representations would be expected to interfere with or delay the acquisition of phonemic awareness, which in turn would lead to difficulties with learning G-P correspondences (Reed, 1989; Share, 1995; Wagner & Torgesen, 1987). They could also disrupt phonological recoding in both lexical access (Denckla & Rudel, 1976) and working memory (Byrne & Shea, 1979; Shankweiler et al., 1979).

These studies indicate the possibility that deficits in phonological perception could exist in some dyslexics at the level of phoneme detection. If some dyslexic children have difficulty with the perception of brief auditory cues (Tallal, 1980) then this would be expected to impair their performance on many tasks of phonological processing. It would be expected to disrupt a child's developing awareness of the phonological structure of words and the establishment of phonological representations of spoken words. Such deficits are likely to be implicated in their difficulties with reading and spelling. Tallal's work is supported by Hari and Kiesila (1996) who found evidence for an association between deficits in auditory perception and developmental dyslexia. A deficit was found in dyslexics, in comparison with normal readers, in the processing of rapid sound sequences, shown in significant delays in their conscious auditory perception. They presented 10 dyslexic adults and 20 controls with trains of binaural clicks, which led to the illusion of sound movements at short, click intervals. The illusion disappeared quickly for controls (at 90-120 msecs intervals) but slowly for dyslexics (250-500 msecs).

Further support comes from Watson & Miller (1993) who analysed the relationships between auditory perception, phonological processing and reading in 94 undergraduates (24 of them with reading disability). The mathematical model which best fitted the data demonstrated that speech perception was strongly related to three out of four phonological variables. These included short and long-term auditory memory and phoneme segmentation which were themselves strongly related to reading ability. Nonverbal temporal processing was not significantly related to any of the phonological variables in the equation. They concluded that speech perception, syllable sequence discrimination and degraded speech tasks may contribute significantly to individual differences in the phonological abilities necessary for skilled reading. However these authors also measured speech perception by a task of speech repetition, which involves setting up a new code for articulation. Consequently it is possible that they were measuring phonological articulation (production) not perception and found this contributed to the individual differences in phonological abilities needed to read successfully.

It has been suggested that developmental lag causes difficulties with speech perception in disabled readers. Hurford & Sanders (1990) compared the performance of second and fourth grade disabled and normal readers while discriminating between combinations of two syllable phoneme pairs. Intervals between the syllable pairs differed within the range identified by Tallal as causing problems for dyslexics. They found normal reading age controls and older disabled readers to be similar in phonemic processing ability. Training in phonemic discrimination improved the performance of younger poor readers and no group differences were found in older children. Manis et al. (1997) also found dyslexic children were poor in comparison to chronological controls but not reading age controls when compared for phonological awareness and phoneme perception. Dyslexics with a low level of phonological awareness, but not those with a higher level, were poor at discrimination in comparison with both control groups. The authors concluded that *some*, not all, dyslexics have a perceptual speech deficit, which may interfere with the processing of phonological information. They also acknowledged that speech perception problems could be related to reading experience. Manis et al. proposed that speech perception deficits could only be found in a *subgroup* of dyslexics and group comparisons of dyslexics and normal readers may obscure this by grouping all dyslexics together.

A growing body of evidence now supports the existence, in *some dyslexics*, of a deficit in identifying and discriminating phonemes but there appears to be agreement that the deficit is small. Overall two methods have been used for identifying deficits in perception, i.e. discrimination of phonemes or repetition of speech with or without noise. Several studies have found differences between dyslexic children and age matched controls in the discrimination of phonemes (Godfrey et al., 1981; Reed, 1989; Werker & Tees, 1987) and the same differences have been found between dyslexic and normal adults (Lieberman, Meskill, Chatillon & Schupack, 1985; Steffens, Eilers, Gross-Glenn & Jallad, 1992; Watson & Miller, 1993). Nevertheless the findings of other studies have not been significant, in some conditions or with some groups, (Brandt & Rosen, 1980; De Weirdt, 1988; Hurford & Sanders, 1990). However even in these investigations dyslexic children were found to be less reliable at discriminating sounds. The pattern of results is similar across studies despite the absence of statistical significance in some. A meta-analysis of all relevant studies could clarify the situation and would be expected to demonstrate an overall statistical significance or trend.

The mixed pattern of results could be a consequence of the difficulty of detection of the small differences involved. Werker & Tees (1987) proposed that small differences in speech perception could be important when learning to read. The insecure phonological categories of dyslexic children could be unsettled by the pressures of beginning to read. This would be a disadvantage at a time when they need to learn orthographic conventions, G-P-C and how to segment words into phonemes. Manis et al. suggested that if this is true it would be expected that children with subtle problems with phonological perception would also have difficulties with tests of phonological awareness. They state that a more explicit level of awareness of the phoneme is needed in tests of phonological awareness than for speech perception tasks. The former usually involve counting, deleting or manipulating particular phonemes within a spoken word whereas the latter generally simply require discrimination between two phonemes (Stahl & Murray, 1994; Yopp, 1988). Manis et al. propose that weak skills of phoneme identification would be heavily burdened by these tasks of phonological awareness.

Manis et al. propose several further reasons for the differing results of various studies. Initially and most importantly speech perception deficits may only be found in a subgroup of dyslexics and group comparisons of dyslexics and normal readers may mask this by grouping all dyslexics together. Secondly the tasks used to measure phonological perception varied in their loading on short term memory which itself is problematic for dyslexics (Bryne & Shea, 1979; Shankweiler et al. 1979). Manis et al. cite an order, of increasing burden on ST memory, for the various tasks used in different studies. They argue that group comparisons using tasks with greater demands on ST memory (e.g. Lieberman et al., 1985; Snowling et al., 1986) have found smaller effects than those using tasks with lower demands on ST memory (e.g. De Weirdt, 1988; Godfrey et al., 1981; Reed, 1989; Werker & Tees, 1987) and that this could be due to the heavier burdens on ST memory. Manis et al. also acknowledge that the smaller effects could be due to the discrimination tasks requiring more fine grained discrimination making them more sensitive to perceptual differences in groups of different reading ability.

Memory.

Several studies have found that problems with phoneme segmentation often exist together with difficulties with verbal memory. This could be caused by a variety of reasons, including, problems with understanding the segmentation task, the memory demands imposed by the task or the type of response required.

A large scale study by Wagner, Torgesen, Laughon, Simmons & Rashotte (1993) examined the relationships between several measures of phonological awareness (including phoneme deletion, sound categorization and sound blending), working memory (memory span and memory for sentences) and naming (letters and digits) in beginning readers and second grade children. They argued that both the phonological awareness tasks and the memory span tasks tapped the quality of underlying phonological representations which affected children's literacy development. Another study by McDougall, Hulme, Ellis & Monk (1994) examined the relationship between memory span and speech rate in good, average and poor readers. Reading skill was found to be associated with short-term memory span but this was accounted for by differences in speech rate. The authors suggested that poor readers had poor memory spans as a result of poor speech rate with the resulting poor processing of information in the articulatory loop. Hulme & Roodenrys (1995) argued that this conflicts with the idea that the ST memory problems of poor readers cause their reading difficulties. They propose that ST memory problems tap other phonological deficits that are actually more easily measured by a task of speech repetition. In their view ST memory problems are an indirect measure of underlying phonological deficits which themselves cause reading difficulties. They stress that the S.T. memory problems of dyslexic children, though adding to their problems when learning to read, do not supply a satisfactory explanation for their serious difficulties with reading.

Hulme & Roodenrys (1995) reviewed the evidence for impairments of memory span in developmental dyslexia finding considerable evidence that dyslexic children had difficulties with digit span tests and other measures of short term memory (Hulme, 1981; Jorm, 1983; Siegal & Linder, 1984). They concluded that dyslexic children use speech coding in an articulatory loop in the same way as normal children but, for dyslexic children, the process works less efficiently. Acknowledging that these short-term memory problems could contribute to the difficulties experienced by dyslexics when they are learning to read they proposed two mechanisms, which could underlie the relationship. Firstly, they suggested that ST memory problems could lead to difficulties with phonic blending. In this way a child when attempting to decode an unknown word could produce possible pronunciations for each component letter which would have to be blended to pronounce the whole word. Beginning readers have been shown to find blending tasks easier if a fast rate of presentation is used (Torgesen et al., 1989) and dyslexic children with low digit span scores have problems with sound blending task in comparison with dyslexic children with normal digit span scores and normal readers (Torgesen, Rashotte, Greenstein, Houch & Portes, 1987). Hulme & Roodenrys used this evidence to support the possibility that ST memory problems make blending phonemes difficult for children. However a fast rate of presentation could not only reduce loading on memory but also guide the child in how to blend the phonemes together in the same way that bringing jigsaw pieces physically closer clarifies the manner in which they fit. Torgesen, Rashotte, Greenstein, Houch & Portes (1987) found that dyslexic children with low digit span scores had problems with sound blending in comparison with dyslexic children with normal digit span scores and normal readers. Hulme & Roodenrys accepted that this could be evidence that the difficulties with phonological processing, experienced by some dyslexic children, could be contributed to by problems with ST memory.

Hulme & Roodenrys also considered the possibility that the ST memory problems of dyslexic children could be the consequence not the cause of their reading difficulties. After examining longitudinal studies where ST memory was measured before children started to learn to read they concluded that memory deficits appear to precede reading difficulties (e.g. Mann & Liberman, 1984), but there was no evidence that they caused literacy problems.

When considering the link between linguistic and immediate verbal memory deficits language disordered children are known to display specific difficulty in immediate auditory memory span. However their difficulties cannot be explained as existing as a result of general verbal ability, speed of articulation or reading ability. It is thought that they have a limited phonological short-term store in working memory. As a result it has been suggested that young language disabled children suffer from a lack of sufficient opportunity to establish "phonological representations" through repetition (Gathercole and Baddeley, 1990). Gathercole and Baddeley (1989) demonstrated, in a longitudinal study, the extent of shared variance between phonological memory and vocabulary growth and in 1990 they proposed a critical period for the influence of phonological memory. It appears that vocabulary, speech and phonology are closely interlinked when "short-term" or "working" memory is associated with the early stages of literacy development. The proposed role of short-term memory in processes as diverse as speech perception, word repetition, parseing, comprehension, and learning to speak and read has lead to considerable research in impaired and unimpaired speakers (e.g. Gathercole & Baddeley, 1990; Howard & Butterworth, 1989; Martin & Breedin, 1992; Vallar & Baddeley, 1987;

1989). Gallagher, Frith & Snowling (2000) have hypothesized that some weaknesses in higher-level skills (i.e. story recall, sentence production) could follow from phonological memory deficits that affect children's early vocabulary development (Bishop, 1997a; Karmiloff-Smith, 1998).

Speech Repetition.

The findings of speech repetition experiments have been variable. Brady, Shankweiler & Mann (1983) found a deficit, in dyslexic children, under noise conditions but two other studies did not (Snowling, Goulandris, Bowlby & Howell, 1986). Snowling et al. did find some differences in the repetition of low frequency words and nonwords, in the noise condition, but argued that they were the result of difficulties with phoneme segmentation. A study by Pennington, Van Orden, Smith, Green & Haith (1990) found no deficits in adult dyslexics. Further studies have found group differences between normal and poor readers when complex multi-syllabic real words (Brady, Poggie & Merlo, 1986) and multi-syllabic nonwords (Kamhi & Catts, 1986; Kamhi, Catts & Mauer, 1990) are repeated. This could be due to poor readers having difficulties with storing and retrieving verbal codes for articulatory expression. Reddington and Cameron (1991) found group differences in the repetition of mono-syllabic words at varying sound intensities. Dyslexics needed the words to be presented at approximately twice the level of sound required by normal readers. However only five of the 17 subjects in the group were responsible for the effect so the authors concluded that only some dyslexics experience speech-processing deficits. Evidence from these studies remains conflicting and even less conclusive than those involving the discrimination of phonemes.

These studies have, however, all suggested deficits in various types of phonological processing as the cause of reading difficulties. Any, either individually or in combination, could be responsible for the difficulties experienced by dyslexics. It follows from this that these various aspects of phonological processing need to be identified and some investigations have attempted to do so. Several studies have used factor analysis to examine the patterns of intercorrelation found amongst the various phonological skills involved in reading. When tasks correlate highly it seems reasonable to expect that they are measuring a common skill. Lundberg, Olofsson & Wall (1980) found high correlations when 143 kindergarten children (average age 7 years) were tested on several measures of phonological awareness. These included ability in the segmentation and blending of syllables and phonemes, locating a target phoneme in a spoken word, reversing phonemes and rhyming. Wagner & Torgesen (1987) reanalysed the data in a factor analysis and concluded that a single ability accounted for much of the variance in the measures of phonological awareness. Stanovitch, Cunningham and Cramer (1984), in a smaller study, gave ten tasks of phonological awareness to 49 kindergarten children (av. age 6 yrs.). Again, with the exception of three tests of rhyming ability, high correlations were found between the tasks. However the children demonstrated ceiling effects on these three tasks of rhyming ability so a separate but undetected rhyming factor could have existed.

Other studies using factor analysis have found separate, but related, factors of phonological ability. Yopp (1988) found two underlying factors from ten phonological tasks (one loaded strongly on tests of phoneme blending, segmentation, counting and isolation and the other on phoneme deletion). However, these two factors correlated highly so they could reflect varying degrees of complication rather than different underlying skills. Rhyming ability was only slightly involved in the two factors so Yopp suggested that rhyme tasks could demonstrate a different ability to other tests of phonemic awareness. Wagner, Torgesen, Laughon, Simmons & Rashotte's (1993) large scale study was described earlier. They found four correlated factors which predicted later reading ability but when acting simultaneously on decoding only phonological analysis predicted first grade reading and only phonological synthesis predicted second grade reading.

Four factors were also found by Shapiro, Nix & Foster (1990). They presented a battery of auditory perceptual processing tasks to 103 children (age 89-160 mths) with reading difficulties and 103 matched average readers. Data from tests of auditory analysis and synthesis, auditory sequential memory, auditory discrimination and phonemic segmentation resulted in four factors of advanced and simple phonological awareness, sequential memory and auditory discrimination. Three of these, but not auditory discrimination, differentiated between the groups with advanced phonological awareness being particularly efficient. The auditory discrimination factor could have failed to discriminate because of the task used for measurement (the Lindamood Auditory Conceptualisation Test). This task is probably insufficiently sensitive to measure discrimination difficulties in children with reading difficulties. The authors concluded that there may not be one underlying phonological ability, which is necessary for the acquisition of adequate reading skill, and that two levels of phonological awareness could exist.

While this thesis was being written up, Muter, Hulme, Snowling & Taylor (1997) published the results of a longitudinal study of 38 children covering their first two years of learning to read. The authors used a battery of tests, measuring the phonological skills of pre-readers, to identify two relatively independent factors, rhyming and segmentation. Their findings suggested that segmentation (measured by phoneme identification and phoneme deletion) was strongly correlated with reading and spelling ability at the end of the first year of schooling but rhyming was not. Further, letter name knowledge predicted both reading and spelling skill and had an interactive effect with segmentation. However, by the end of the second year of school, rhyming (measured by rhyme detection and rhyme production) had begun to predict spelling but not reading.

These factor analyses do not provide a simple account of the phonological skills necessary for children to learn to read. However phonological awareness tasks do seem to be highly correlated which indicates that there is likely to be one main factor of phonological awareness. Some studies have split this overall factor into highly correlated sub-factors that were predictive of later reading ability. Distinguishing between these sub-factors is of great importance if they vary in their ability to predict reading. Interestingly different factors were found to predict reading ability at varying times in the development of literacy. This supports a developmental view of reading where these skills develop at different times and have varying relationships with reading skill (e.g. Frith). Individual differences in various aspects of phonological processing have been found in these studies. Skill in phonological processing (depending upon the particular procedure involved) could embrace several or all of the following component abilities, phonological awareness, phonological memory, phonological perception, setting up a new phonological code for articulation and the segmentation and blending of phonemes and syllables. Deficits in any one or any combination of these could result in difficulties with reading and/or spelling. It is not yet known how many phonological skills exist or which are essential to, and which less important for, the normal development of literacy in a child.

The RS theory predicts the existence of at least two types of difficulty with literacy, which occur naturally, as a result of individual differences in patterns of cerebral specialization. These risks are illustrated in figure 1.4. The rs-- genotype is expected to be at risk for deficits in phonological processing and weak phonology has been found, in several samples of children and undergraduates, in those with faster left than right hands (Annett, 1991; 1992a; Annett, Eglinton & Smythe, 1996). The question now arises of which aspect (or aspects) of phonological processing is (or are) associated with a reduction in dextrality (and so, by hypothesis, the rs-- genotype). The aim of this study was to attempt to distinguish various specific aspects of phonological processing and identify which, if any, are associated with reduced dextrality. Annett (1991) suggested that the critical developmental variable could be whether speech output and input are controlled from the same side of the brain so it was expected that difficulties with phonological production or perception would be associated with reduced dextrality (and the rs-- genotype). A specific phonological deficit of this type would be expected to affect the normal development of reading and spelling ability. However, before attempts to separate the various components of phonological processing could begin it was necessary to test the hypothesis of the RS Theory that there are risks to phonological processing in those with reduced dextrality. Consequently this led to the following two questions for investigation: -

1) Is poor phonological processing associated with a reduced bias to dextrality?

2) What are the components of poor phonological processing and are all or some associated with reduced dextrality?

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Chapter 2

Methodology Overview

This research was based on three sets of experiments which involved (i) a single year cohort of schoolchildren from nine schools followed up over 3 years (Wellcome), (ii) unselected samples of undergraduates (Word) and (iii) a sample of undergraduates which was selected to include a substantial number of left and mixed handers (Spooner). This chapter outlines the three different methodologies involved.

Unless stated otherwise statistical analyses throughout the thesis were accomplished using an SPSS computer software package, were one tailed and where appropriate used Least Significant Difference contrasts.

1) The Wellcome Trust Schools Project.

The Wellcome Trust schools project was a cross-sectional study of a representative cohort of children in normal schools with longitudinal follow up of children of interest for 2 further years.

Participants

The total sample consisted of a complete year cohort of 9-10 year olds, in nine schools, who attended school on test days. The Senior Educational Psychologist recommended the urban, suburban and rural schools as being representative of the local educational authority (LEA).

First Year. The total sample consisted of 479 children tested, in class, using group tasks. Initially the sex ratio was almost precisely equal with 240 girls and 239 boys. The mean age was 121.4 months with a standard deviation of 3.5 mths. and a range of 115-128 mths.

Second Year. Follow-up individual tests were given to 199 girls and 192 boys (mean age 134.7 months, SD 3.6 mths., range 127-141 mths).

Third Year. Additional follow-up tests were given to 61 girls and 67 boys (mean age 145.8 mths., SD 3.5 mths., range 140-153 mths.). This resulted in a highly selected third year sample that is not representative of the population as a whole. Tests of laterality were also given to 51 children not seen in year 2 giving a total of 442 children being individually assessed for handedness and hand skill.

Before any analysis that involved literacy could begin 20 children with recognised special needs had to be excluded. This was because either their first language was not English or their scores were unusable due to severe physical or mental disabilities. This left 459 children in the main sample. One further child, with a history of severe damage to his left arm, was excluded for analyses that involved hand preference or hand skill.

Design.

The study was designed to be cross-sectional with longitudinal follow up for specific cases. Group tests (given in classes) were used in the 1st. year in order to sample a complete cohort of 9-10 yr. olds. Results from these tests were used to assign children to various groups of differing laterality, literacy and cognitive abilities. Richmond tests were given routinely by most of the schools and the results were made available to us. Some first year analyses, in this thesis, made use of the Richmond vocabulary scores.

Second and third year follow up tests were administered individually to children who had been selected as being particularly interesting on the basis of the 1st. year assessment. In year two, all children with scores that were at least one standard deviation below the mean, on any cognitive test in year 1 were revisited. As many controls as possible were also seen at the year 2 follow up and in total approximately 80% of the initial cohort were seen individually in that year. Absentees and children who changed to another school, which was being visited, were seen, when possible, at follow up.

The final assessment in year 3 was again conducted on an individual basis, testing children with literacy problems and controls so that approximately 25% of the initial sample were tested for a third time. Where possible, controls who had been missed in year 2 had their hand preference and peg board skill recorded in year 3 to increase the representation of these individual measures. Family handedness data was also collected in year 3 by distributing sets of hand preference questionnaires to the families of children in the classes of the original cohort.

Teachers were initially asked to identify children with specific difficulties in reading and spelling, whether present or past. They were also asked, at subsequent visits, for comments on children of interest.

Procedures and Tests

The test numbers assigned in this chapter are used throughout the thesis and full details of each test are to be found in the relevant chapters.

Year 1 (Class Tasks).

Tasks were all presented, in class in one double period of approximately 45 minutes, by Annett plus a research assistant and in the presence of a teacher. They are listed below, in order of presentation. Copies of specimen materials are to be found in appendices as indicated.

No.	Name	Relevant Appendices	Assessment
1.1)	Hole punching task.	W	*Laterality*
1.2)	Word Order Memory Task	B	*Phonology/ Auditory Memory*
1.3)	Word Discrimination Task	D	*Literacy*
1.4)	Spelling Task	C	*Literacy*
1.5)	Non-word Spelling Task	E, G	*Phonology/ Auditory Memory*
1.6)	Space Task	F	*Visual Memory*

Year 2 Tests (Individual Assessment).

Children were removed from class in pairs and seen individually by two experimenters; these were usually Annett and Eglinton or Annett and myself (Smythe) working in parallel (as described in Annett, Eglinton & Smythe, 1996). Testing took approximately twenty minutes per child. Care was taken to position the two testing tables at the maximum distance apart with the two children facing away from each other so that they should not have been able to hear the other child's response. However, two parallel versions of the word tests were used to ensure that the children were required to give different responses. See appendices as indicated for specimen materials.

No.	Name	Appendices	Assessment
1.8)	Peg Board Task	U	*Laterality*
1.9)	Hand Preference	A, K	*Laterality*
1.10)	Matrices Intelligence (CPM).		*Cognitive Ability*
1.11)	Word Reading (B.A.S.)	I	*Literacy*
1.12)	Phoneme Segmentation Task	H	*Phonology*
1.13)	Visual Task	J	*Visual Memory*

Year 3 Tests.

Again children were taken from class in pairs and tested individually, for approximately twenty minutes, by two experimenters (usually Annett and Eglinton or Smythe). In each pair one child wore headphones for the computer tasks while the other was reading and doing other tasks. Specimen materials are available in appendices.

No.	Name	Relevant Appendices	Assessment
1.14)	Auditory Memory task (digit span).		*Phonology*
1.15)	Reading Task (Schonell and Schonell, 1952)		*Literacy*
1.16)	Spelling Task	C	*Literacy*
1.17)	Auditory Discrimination Task	L	*Phonology*
1.18)	Nonword Repetition Task	M	*Phonology*
1.19)	Nonword Reading Task	N	*Phonology*
1.20)	Family Handedness	O	*Laterality*

Other tasks

Other tasks (two computer administered) were presented on the same occasion but have not been used in this thesis so they will be described elsewhere.

Note: The phoneme segmentation test (1.12) was adapted by me from tasks designed by Stuart (1990) and Bruce (1964) for use with children. I also adapted lists of nonwords from PALPA Kay, Lesser and Coltheart (1992) for the three tasks of auditory discrimination (1.17), nonword repetition (1.18) and nonword reading (1.19). Details can be found in the relevant chapters and wordlists in appendices H, L, M and N.

Undergraduate Experiments.

2) "Word Processing" in Unselected Undergraduates.

This was supervised third year student project research using year 1 students as participants in order to collect data on word processing (and other cognitive abilities) in 3 year-cohorts of undergraduates.

Group tests (given in classes) were used in order to sample a cohort of undergraduates, over three years. Test details can be found in chapter 6. Results from these tests were used to assign undergraduates to various groups of differing laterality, literacy and cognitive abilities. Other tests of cognitive ability were administered, by the experimenter, on the same occasion but these are not relevant here and so will be described elsewhere.

Participants

Participants were 321 (259 females, 62 males) first year psychology undergraduate volunteers from Leicester University whose ages ranged from 18 - 48 yrs (mean age 20.5 yrs, S.D. 5.5).

Year 1 - 139 subjects (115 females and 24 males) took part in the first year of testing.

Year 2 - 89 subjects (68 females, 21 males), took part in the 2nd. year of testing.

Year 3 - 93 subjects (76 females, 17 males), took part in the 3rd. year of testing.

Before analysis data from 23 subjects who had not learned English as their first language or whose first language was unknown were removed.

Design.

The design of the study was a cross sectional cohort of first year undergraduates collected over three years.

Tests

No.	Name	Relevant Appendices	Assessment
2.1)	Pegboard Hand skill	U	*Laterality*
2.2)	Hand Preference	A, K	*Laterality*
2.3)	Family handedness	O	*Laterality*
2.4)	Benton Phoneme Discrimination Test	Q	*Phonology*
2.5)	Rhyming Nonword Decision Task	P	*Phonology*

Note: - The rhyming nonword decision task was adapted, by me (Smythe), using rhyming and non-rhyming nonwords from Besner, Davis and Daniels (1981). I also included the

Benton Phoneme Discrimination task; see chapter 6 for details and appendices P and Q for word lists.

3) Spooner. Phonological Processing in Selected Undergraduates.

The Spooner project was run over three years in order to collect three approximately equal groups of first year undergraduates with different hand preferences (pure right, mixed right and pure plus mixed left).

Participants.

Participants were recruited to give (a) 38 pure right-handers, (b) 44 mixed right-handers and (c) 41 pure + mixed left-handers. These groups were established from the 12 actions identified in the Annett Hand Preference Questionnaire (Annett, 1970a).

All subjects (n= 123) completed a common set of tests (3.1-3.8). Sixty-four of these also completed additional tests (3.9-3.11). Most subjects (118) came from Leicester University and five came from other universities (recruited from personal contacts). They had a mean age of 20.9 yrs. (S.D. 5.75, range 31 yrs., min. 18, max. 49). Before analysis data from one participant, who was profoundly deaf, and from 8 subjects whose first language was not English were removed.

Year 1 - 59 subjects (34 females and 25 males) took part in the basic tests (3.1- 3.8 below). They were all first year university students, between the ages of 18 and 43 years (mean 20.0 yrs., S.D. 4.2 yrs., range 25 yrs., min 18 yrs., max. 43 yrs.) who volunteered to take part.

Years 2 and 3 - 64 subjects (34 females, 30 males) took tests 3.1- 3.8 plus the additional tests introduced in years 2 and 3 (tests 3.9-3.11 below). They were all first year undergraduates at Leicester University (mean 21.6 yrs., S.D. 6.5 yrs., range 31 yrs., min. 18 yrs., max. 49 yrs.).

Design.

The design of the study was cross sectional, over three years, with three approximately equal sized groups of first year undergraduates who exhibited different hand preferences (pure right, pure left and mixed). The first step was to screen the whole sample for hearing deficits.

Procedure.

Tasks 3.1-3.8 were presented over all three years of data collection but the more specific phonological tasks (3.9-3.11) were presented only in the latter two years. In each case subjects were tested individually in a quiet room. Task details may be found in chapter 7 and specimen materials in appendices P to T. The speech tests preceded the dichotic listening task. Data from measures of laterality were available, for most subjects, from an earlier laboratory practical. When this was not available the experimenter individually observed hand preference and timed hand skill for moving pegs.

Tests Taken by All Subjects.

No.	Name	Relevant Appendices	Assessment
3.1)	Hand preference	A, K	*Laterality*
3.2)	Peg Board Hand skill	U	*Laterality*
3.3)	Family handedness	O	*Laterality*
3.4)	Hearing Test.		*Auditory*
3.5)	Spoonerisms (Perin, 1983)	R	*Phonological*
3.6)	Auditory Acronyms (Wilding, 1990)	S	*Phonological*
3.7)	Rhyming Nonword Decision Task	P	*Phonological*
3.8)	Dichotic Listening.		*Auditory Perception*

Year 2 and 3 Tests.

The above tasks were administered in years 1, 2 and 3 but the additional tasks, described below, were given in the second and third years.

No.	Name	Relevant Appendices	Assessment
3.9)	Digit Span WAIS-R (forward only).		*Phonology*
3.10)	Benton Phoneme Discrimination	Q	*Phonology*
3.11)	Nonword Repetition	T	*Phonology*

Note: - The auditory acronym task was adapted, by me, from a triplet task used by Wilding (1990, and based on an earlier study of Campbell and Butterworth, 1985). I also developed a nonword repetition task using multi-syllabic nonwords from Campbell and Butterworth (1985). See appendices S and T for wordlists.

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Chapter 3

Two Experiments on Phonology in Schoolchildren.

This chapter describes two experiments on phonology which were part of the Wellcome project. Both experiments involved schoolchildren. Participants in the first experiment were an entire age cohort of 9-10 year olds, in nine schools. The second experiment includes many of the same children seen at follow up, one year later. The first experiment used a group test of phonology (nonword spelling) while the second used an individual test (phoneme segmentation) which relies on real words for both stimuli and most correct responses.

EXPERIMENT 1

Group tests of nonword spelling and a hole punching test of laterality in a representative sample of 9-10 year olds (year 1).

Introduction.

Work on this thesis began with the question of whether poor phonological processing, as measured by a group test of nonword spelling in the entire age cohort, was associated with a reduced bias to dextrality. If this is so then children who are poor at a nonword spelling test will be to the left of the continuum of handedness, in a hole punching task, when compared with those whose nonword spelling is normal or good. In accordance with predictions of the RS theory, this is expected to be found in children with no other evidence of developmental pathology except a specific difficulty with phonological processing.

Performance in nonword reading is widely used as a criterion for identifiying phonological dyslexics (see literature review). It gives a relatively direct indication of phonological reading skill (Snowling et al., 1991) so problems with the task are expected to imply underlying phonological deficits. However the first analyses below used nonword *spelling* ability as a measure of phonology and there have been fewer empirical investigations of the spelling performance of dyslexic children than of their reading abilities. Rohl & Tunmer (1988) found that average and good spellers performed better than poor spellers on phoneme segmentation tasks, made fewer errors when spelling non-words and made spelling errors which were more phonetically accurate. Bruck & Waters (1988) showed that poor spellers had problems with the phonological aspects of spelling and these were especially associated with converting sounds into the appropriate graphemes in the correct order. Further, Stuart (1990) found that poor spellers had more problems with a phoneme segmentation task than good spellers.

The following analysis used nonword spelling as a test of phonological processing to investigate the relationship with laterality predicted by the RS theory. This first analysis of nonword spelling provided an efficient method of screening the whole cohort as it was run for the whole sample as tested, in class, in year one. Frith has argued that normal children first use and learn G-P-C skills in spelling, and only later transfer them to reading, so this first screening was expected to tap this early ability.

The RS theory predicts that individuals with specific deficits of phonological processing will be less dextral than the majority. This, however, does not include individuals with a generally low level of ability as their deficits could be due to pathology rather than effects of the RS locus. Consequently, the effects of the rs+ gene should be more detectable in able children with poor phonology. To test this the analyses were repeated initially after the exclusion of subjects with hole scores of 25 or less on either hand (2.5 s.d.s below the mean and likely to be pathological). Following this children with a very low Richmond Vocabulary were excluded as they may not have responded to the nonword spelling test. After these selections for ability it was expected that pathological left and right handers would have been excluded so differences between the groups in handedness were expected to increase.

Method.

Participants - The total cohort included 479 (240 girls and 239 boys) schoolchildren (mean age 121.4 months). Before any analysis which involved literacy was performed 20 children with recognized special needs were excluded leaving 459 children in the main sample. The excluded children either did not have English as their first language or their scores were unusable due to severe physical or mental disabilities. One further child identified later, with a history of severe damage to his left arm, was excluded for analyses that involved hand preference or hand skill.

Design - The present analysis uses tests of nonword spelling and hole punching. These were designed for a cross-sectional survey of the whole cohort of 9-10 year olds in 9 schools in the first year of the research.

Procedure. -

1.1: Hole punching task (laterality, first year) Annett (1992d). The aim was to use a fine pointed ball pen to punch holes inside small circles, which were printed in six pairs of parallel rows, on a single sheet of stiff A4 paper (see appendix W). The circles were 1.5 mm diameter and 10 mms apart. Punctures were made as rapidly as possible and the instruction was to punch as many holes as possible in 15 seconds, alternating between upper and lower printed rows for each pair of holes (as indicated in diagram in appendix W). Support for the paper was provided by a wooden board with 3 mm holes beneath each circle to allow punctuation of the paper. Subjects were allowed one practice trial (for each hand) and then attempted two test trials (per hand) beginning with the right hand and alternating hands (RLRL). The total number of holes punched by each hand, in both trials, was scored. Most of the following analyses use the measure of difference between the hands expressed as a proportion of the total number of holes made by both hands (holeperc).

$$R\text{-}L\%\ HOLES = (((R-L)/(R+L))\ X\ 100).$$

Richmond Vocabulary Test (literacy, first year). The Richmond tests are tests of educational attainment which were used in most of the schools. Results were made available, from teachers records, at 7 of the 9 schools. These included a vocabulary test score (mean 103.7, sd 13.8, range 62, min. 69, max. 131).

1.5: Non-word Spelling Task (phonology, first year). The stimuli were 6 pretend words adapted from simple real words by replacing one letter with a substitute (gouse, dunny, charch, toble, fape and nater) as can be seen in appendix E. They were presented auditorily and immediately following a real word spelling test. The children were instructed that the experimenter was about to say some words which they were to write down. Their instructions were -

' If you are not sure how to spell them, it doesn't matter. Just do the best you can. Some of them will be pretend words so they cannot be right or wrong. I would like you to show me how you think they could be spelled.'

The nonwords were read clearly, and repeated once, with 5 seconds between items. The task of marking and analysing nonword spelling errors was assigned to me (Smythe) and was conducted blind to information on other tasks. Any nonword spelling response was allowed if when pronounced, by the experimenter, it sounded like the target (e.g. "gouss" and "gaus" were accepted for the spelling of "gouse" but not "gose", "gawbs" or "gouth", see appendix G for a full list of accepted nonword spellings).

Groups with 0-3 and 4-6 nonword spelling errors were compared, for the holes measure of hand skill, by SPSS t-test. SPSS chi-square was used to compare hand dominance (assigned by their better hand on the first year holes test). Comparisons were made both before and after selection to remove (a) those with particularly slow hand speeds and (b) those with low Richmond vocabularies. Finally a full Bonferroni correction was used on both sets of analyses. In all analyses it was predicted that the group with most errors would be least dextral and that the effect would increase with selection for ability.

Results.

Nonword Spelling: Most children (79%) could produce four or more (from a possible six) acceptable nonword spellings and only 2.8% failed to produce any. Table 3.1 gives the mean number of nonword spelling errors plus standard deviations for the whole sample and the two groups together with the range of the whole sample.

Table 3.1: Mean Nonword Spelling Errors of Nonword Spelling groups

Group	Mean	Std. Dev.	N.
Whole sample (range 6, min/max. 0/6)	1.323	1.525	455
3 or less nonword errors	0.978	0.990	398
4 or more nonword errors	5.382	0.493	57

Groups for comparison for mean hole punching skill were divided at approximately one standard deviation above the overall mean for nonword spelling so that the many error group made four or more errors and the few error group made three or less errors.

a) Hand Skill (holeperc). The whole group had a mean R-L% hand skill of 16.9 (s.d.15.9, range 122.1, min. -45.2, max. 76.9) for the holes punching task. Table 3.2 gives the means and standard deviations of the two nonword spelling groups (0-3 errors and 4-6 errors) before selection and after selection for hand skill (25+ on the holes test) and for two levels of vocabulary (70+ and 90+). Figure 3.1 illustrates the mean hand skill of each nonword spelling error group before and after the progressive selections.

Table 3.2: Mean Hand Skill of Nonword Spelling groups before and after Selection to Remove those with Slow Hand Skill and Low Vocabulary

Selection	Group	Mean Holeperc	Std. Dev.	N.
Unselected	0-3 nonword errors	17.2	15.6	398
	4 + nonword errors	15.0	17.7	57
holes > 25	0-3 nonword errors	16.6	14.2	370
	4 + nonword errors	12.5	17.6	49
vocab. > 70 *	0-3 nonword errors	16.8	14.3	309
	4 + nonword errors	11.7	17.2	42
vocab. > 90	0-3 nonword errors	16.9	14.5	282
	4 + nonword errors	7.4	21.7	20

* a statistically significant contrast

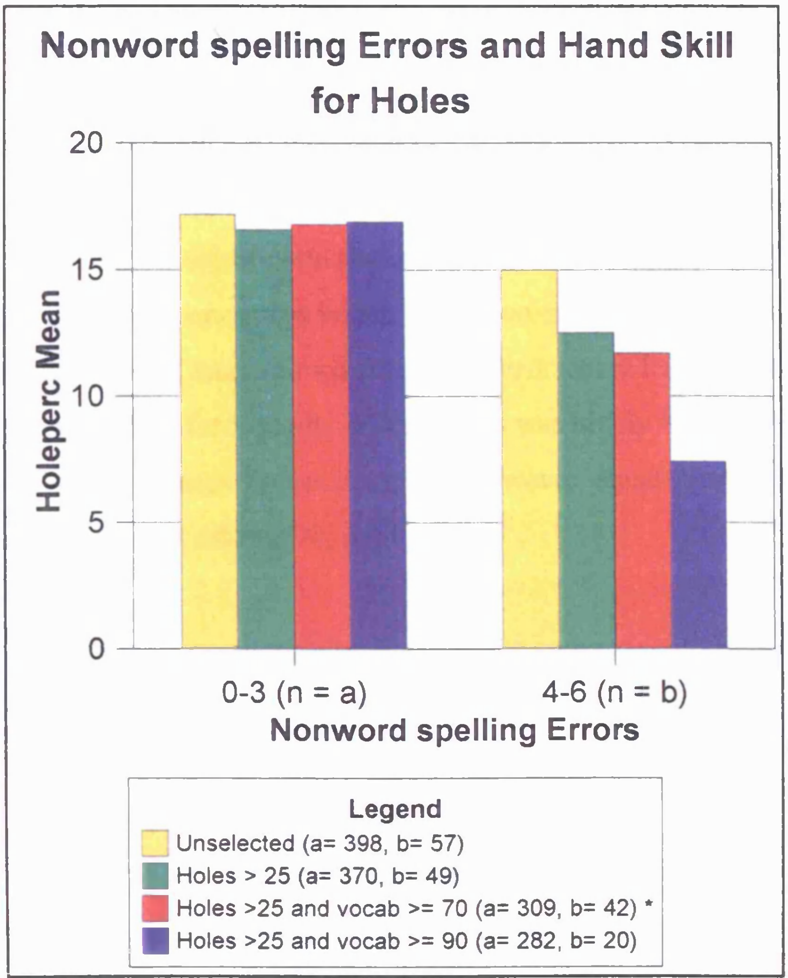

Figure 3.1: Mean hand skill for hole punching of children with few (0-3) and many (4-6) nonword spelling errors. (*Unselected* - the whole sample, *Holes > 25* - minus children with slow hand skill, *Holes > 25 and Vocab >= 70* - minus children with slow hand skill and vocabulary < 70, *Holes > 25 and Vocab >= 90* - minus children with slow hand speed and vocabulary < 90.) * A statistically significant contrast.

Taking the whole sample the contrast between group mean hand skill was in the predicted direction but not statistically significant (t (453)= 0.94; p> 0.1). After removing children with slow hand speeds (holes <25), the contrast between groups was again not significant (t (56.6)= 1.57; p> 0.1). In this analysis Levene's Test for Equality of Variances was statistically significant (F= 4.446, p= 0.036) so unequal variances figures are cited.

Following further selection, to remove children with very low vocabulary scores (< 70), the contrast between groups was statistically significant (t (349)= 2.11; p=0.036).

Children with more nonword spelling errors were increasingly less dextral than those with few. Levene's Test for Equality of Variances was not violated so equal variance figures are cited.

An additional selection to remove children with poor vocabularies (< 90) resulted in a contrast between groups which was a non-significant trend ($t\ (20.23) = 1.91$; $p=0.07$). Children with more nonword spelling errors were less dextral than those with few. Levene's Test for Equality of Variances was highly significant ($F= 12.21$, $p= 0.001$) so unequal variances figures are cited. However, equal variance figures were highly significant ($t\ (300)= 2.70$, $p = 0.007$).

A full Bonferroni correction for multiple comparisons required a significance level of 0.013 which was not reached by any of the present analyses.

Discussion

Although most analyses were not statistically significant it can be seen from figure 3.1 that differences between the mean hand skill, of the many and few nonword spelling error groups, increased with selection to remove those with slow hand speed and a vocabulary of less than 70. This was largely because the means of the many error group moved progressively further from dextrality with each selection while the means of the few error group remained largely unchanged. However the number of participants in the many errors group became much smaller after selection to remove children with a vocabulary of less than 90 and this is likely to be the cause of the lack of statistical significance in this final comparison. However a full Bonferroni correction resulted in no statistical significance for any of the comparisons.

b) Faster hand (on the Holes Test).

The holes test gives a bimodal distribution of responses and was found to give the greatest separation between hands in the performance of five tasks of hand skill (Annett, 1992d). Consequently the faster hand on this task was used here to give an indication of the preferred hand. The left hand was faster if R-L holes was less than 0 and the right was quicker if R-L holes was above 0.

Results

The whole group included 9.4% with faster left hands on the holes task. Table 3.3 gives the number with faster left hands in each of the two nonword spelling groups (0-3 errors and 4-6 errors) before selection and after selection for slow hand skill (25+ on the holes test) and after selection for two levels of vocabulary (70+ and 90+). Figure 3.2 illustrates the percentages of each nonword spelling error group with a faster left hand on the holes test before and after the progressive selections.

Table 3.3: Faster Left Hand and Nonword Spelling groups before and after Selection to Remove those with Slow Hand Skill and Low Vocabulary

Selection	Group	Faster L. Hand	(%)	N.
Unselected	0-3 nonword errors	37	(9%)	398
	4 + nonword errors	8	(14%)	57
holes > 25	0-3 nonword errors	33	(9%)	370
	4 + nonword errors	8	(16%)	49
vocab. > 70	0-3 nonword errors	27	(9%)	309
	4 + nonword errors	7	(17%)	42
vocab. > 90 **	0-3 nonword errors	26	(9%)	282
	4 + nonword errors	6	(30%)	20

** A highly statistically significant contrast

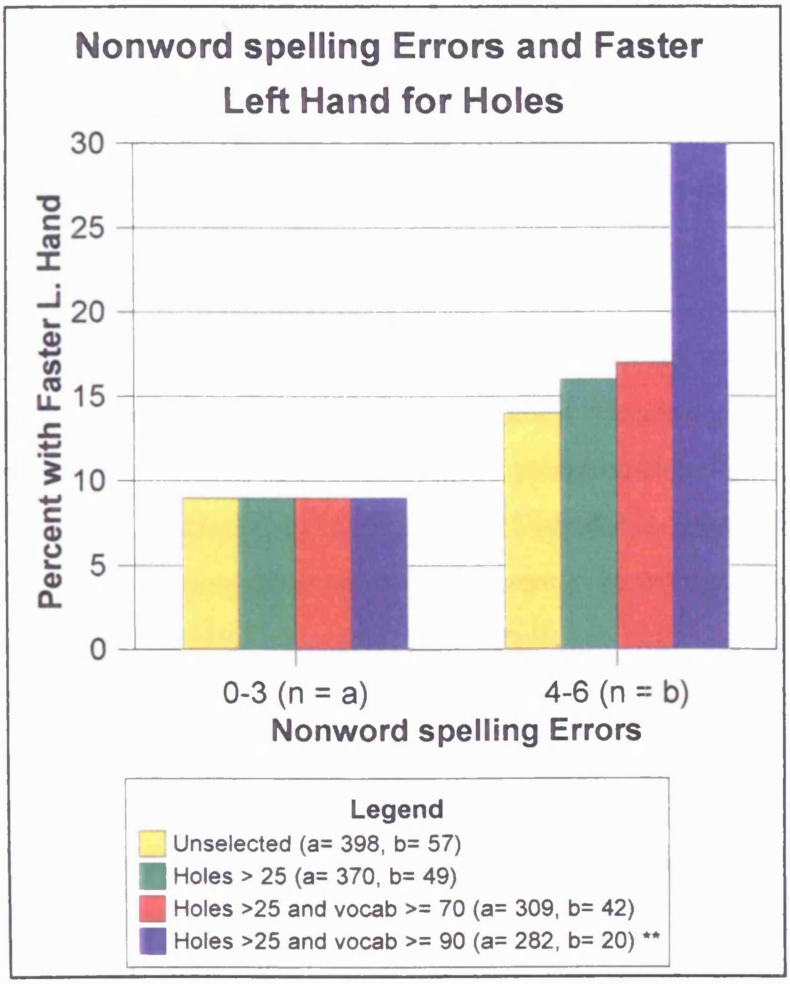

Figure 3.2: Percentages of children with few (0-3) and many (4-6) nonword spelling errors who are faster with their left hands on a hole punching task. (*Unselected* - the whole sample, *Selected: Holes > 25* - minus children with slow hand skill, *Selected: Holes > 25 and Vocab >= 70* = minus children with slow hand skill and vocabulary < 70, *Selected: Holes > 25 and Vocab >= 90* = minus children with slow hand speed and vocabulary < 90.) ** A highly significant contrast

In the whole sample children making more nonword spelling errors (4+) were more often faster with their left hands (14%) than children with fewer errors (9%) but this was not statistically significant (chi-square (1) = 1.25 p > 0.1).

After removing children with slow hand speeds (holes <25) 16% of the high error group and only 9% of the low error group were faster with their left hands. This trend was in the expected direction but not statistically significant (chi-sq. (1)= 2.689, p = 0.101).

Further selection to remove those with holes < 25 and vocabulary < 70 found 17% of the high error group and 9% of the low error group were faster with their left hands. The trend was again in the expected direction but not significant (chi-sq. (1) = 2.657, p = 0.103).

A final selection to remove those with holes < 25 and vocabulary < 90 found 30% of the high error group were faster with their left hands compared with 9% of the low error group. This difference was in the predicted direction and highly statistically significant (chi-sq.(1)=8.513, p=0.004; Fisher's Exact p = 0.012). Children with more nonword spelling errors were less frequently dextral than those with few. Including subjects with slow holes scores still resulted in a high statistical significance (Chi-sq. (1) = 7.358, p=0.007).

As found above for hand skill the percentage with faster left hands in the low error group remained stable with selection to remove those with slow hand speeds and low vocabulary scores. In contrast, as can be seen in figure 3.2, the percentage with faster left hands in the many error group increased dramatically with selection.

A full Bonferroni correction for multiple comparisons required a significance level of 0.013 which was reached, in the present analyses, only after the final selection to remove those with slow hand speed and low vocabulary.

Discussion.

This first year group test screened the entire cohort of 455 schoolchildren for hand skill and nonword spelling difficulties. Results for analyses before selection, and some after selection, were not statistically significant. However, after progressive selection to remove those children with slow hand skills, and poor vocabularies, differences between groups in handedness became statistically significant with the faster hand on the holes test analysis (although not the hand skill analysis) being highly statistically significant (and still statistically significant after using a full Bonferroni correction).

The use of the Bonferroni correction in this type of analysis is debated (Perneger, 1998) as it was developed for repetitive situations (e.g. quality control). In this experiment each analysis was selected to include progressively more able children - a theory led decision. However even when the stricter criterion of a Bonferroni correction was used the results, for the faster hand on the holes test, still support the hypothesis (of the RS Theory) that difficulties with phonological processing, which are found in children to the left of the handedness continuum, are not merely due to 'pathological' handedness.

It can be seen from figure 3.2 (and figure 3.1) that the few nonword spelling error group means for handedness remained remarkably stable after successive selection for ability while the many error group means became progressively less dextral. This decrease in dextrality amongst those with phonological difficulties but not vocabulary or hand speed problems makes it unlikely that "pathological handedness" is responsible for the handedness effect. Selection for ability resulted in an increase in sinistrality for the group with phonological problems. If it were the case that "pathology" alone was responsible for the sinistrality of the group with phonological problems then selection for ability would have resulted in a decrease in sinistrality of that group. This clearly did not happen.

This supported predictions of the RS theory that statistically significant effects for laterality are likely to be found in children with no other evidence of developmental pathology except a specific difficulty with phonological processing. Specific difficulties are likely to be involved here because removing children with slow hand speeds and low vocabularies increased the effect for handedness.

A nonword spelling task was used in this experiment to screen a whole cohort of 10 year olds for phonological problems. The ability of the nonword spelling task to tap phonological difficulties was supported by subsequent factor analyses (reported in chapter 5) which showed nonword spelling errors loaded strongly with other, later, tests of phonological processing. In addition Frith has argued that, in normal children, alphabetic skills first emerge in spelling and are only later transferred to reading. She proposed that normal children first learn and use grapheme phoneme conversion skills in spelling. All of these factors support the use here of a nonword spelling task as an appropriate and efficient method of screening the whole cohort for phonological difficulties.

Comparisons reported here, between children who were good or poor at nonword spelling, supported the prediction made by the RS theory that poor ability in phonological processing is associated with a reduced shift to dextrality although some were not statistically significant. However, the present results could be interpreted as reflecting a specific difficulty with nonwords instead of a purely phonological problem. To investigate this further the following experiment used a task of phoneme segmentation which used real words as both stimuli and responses to confirm that a phonological difficulty is being examined not just a specific difficulty with one measure of phonological processing.

EXPERIMENT 2

Individual tests of phoneme segmentation and peg moving in 10-11 year olds (yr 2)

Introduction.

The next question for investigation was whether poor phonological processing is associated with a reduced bias to dextrality when it is measured by a phoneme segmentation task which used real words, not nonwords, for both stimuli and responses. The main hypothesis was that children who are poor at the phoneme segmentation task (demonstrating poor phonological processing using a majority of real words) would be to the left of the continuum of handedness, on the peg board task, in comparison to those with no problem.

The opportunity to test children individually for phoneme segmentation came in the second year follow up. Year 2 tests were planned to make individual assessments of all children who were poor (1 s.d. below the mean on any year 1 test) plus control children. The responsibility for designing the assessment of phonology was assigned to me. I adapted a phoneme subtraction form of a phoneme segmentation task which was originally devised by Bruce (1964) and modified by Stuart (1990). Instructions given to participants requested that a word was repeated but minus a sound (eg. 'jam' to 'am'). However, two responses were possible to 6 of the 10 items in the phoneme segmentation task (phonological or orthographic). Phonological responses involve deleting a *sound* ('pint' to 'pine') from a word whereas orthographic responses are arrived at by deleting a *letter* ('pint' to 'pin'). Consequently a strict scoring criterion would count only a phonological response as correct. However, the purpose of this task was to measure ability at phoneme segmentation not ability to carry out instructions. Stuart demonstrated that children who were good readers and spellers made more orthographic responses to a task of phoneme segmentation than did poor readers and spellers. If this is true then accepting orthographic responses as correct is necessary, for the present purposes. If orthographic responses were rejected, good readers and spellers would be penalized for using a favoured and efficient strategy, not for having poor phonological processing abilities. In order to resolve this point a partial replication of Stuart's study was necessary to test whether, in this experiment, children who make many orthographic responses to a task of phoneme segmentation are good readers and spellers. This was necessary for two reasons, initially to validate the test of phoneme segmentation and secondly to confirm that the acceptance, as correct, of orthographic responses was justified in later analyses. The hypothesis of this preliminary analysis was that children who make several orthographic responses to the phoneme segmentation task are better readers and spellers than those who make few.

Consequently a preliminary analysis (a) explored the spelling and reading abilities of groups of children who vary in their use of an orthographic strategy for a phoneme deletion task. It was expected that as orthographic responses increased reading and spelling errors would decrease. Following this preliminary analysis the hypothesis was tested that children making many errors on the phoneme segmentation task would be less dextral than a group making few errors (analysis b).

Three types of response were possible to this segmentation task (i.e. errors, phonologically correct or orthographically correct). It was hypothesized here that children who varied in their main type of response could also vary in the stage of literacy development which they have achieved. Frith's three stages of normal literacy development have been outlined in the literature review. In the first (logographic) stage children have not yet learned to decode unfamiliar words so they use visual resemblances to known words to help them in recognition. The second (alphabetic) stage begins when the child has learned relationships which exist in their language between sounds and letters. Finally the child learns to analyse words into orthographic units without resorting to phonological conversion (eg. 'tion' is immediately recognised). They now have internal representations of abstract strings of letters and these can be used without the need for "sounding out". Frith suggested that "classic" developmental dyslexia arises when a child fails to break through to the alphabetic stage so that reading and spelling remain stuck in the logographic stage.

If good readers and spellers do use an orthographic strategy for phoneme segmentation (Stuart, 1990) this could correspond with Frith's final, orthographic stage. Children in the three different stages could vary in their responses to the task of phoneme segmentation. Those still in the logographic stage could predominantly make errors, those in the alphabetic stage would make phonological but not orthographic responses and those in the final stage would make mainly orthographic responses. If this is true then the three groups would also vary in reading and spelling ability. Those with most errors would be expected to be least good at both reading and spelling while those with predominantly orthographic responses would be anticipated to be best at reading and spelling.

It is possible that children who vary in ways which correspond with Frith's stages of literacy development could also vary in handedness in accordance with expectations of the RS theory. In order to break through to an alphabetic stage a child would be expected to have reasonably adequate phonological processing abilities. Consequently it can be assumed that those who fail to break through have deficits in phonological processing. A group with problems in breaking through to an alphabetic stage could have the phonological problems predicted by the RS theory. The theory predicts that in a cohort of children, those with a specific phonological problem are likely to be less shifted to dextrality, as a group, than those without these difficulties. It could be that the phonological deficit which is predicted by the RS theory is one which also prevents children from accessing an alphabetical stage. Frith's stages are a developmental progression and it is not proposed here that handedness changes with literacy development. However it is proposed that in a large sample of children of the same age those who have not yet broken through to the alphabetic stage are likely to include some with phonological deficits due to absence of the rs+ gene. If this is true then those children who are arrested at a pre-phonological stage, as a result of a phonological problem, will be less shifted to the right for handedness, as a group, than children who do not have such problems. It was therefore expected that groups making many segmentation errors, many phonological responses or many orthographic responses would also vary in their handedness. The error group would be predicted to be less dextral than the phonological or orthographic response groups.

In order to investigate this hypothesis groups of children were distinguished using their responses to the phoneme segmentation task (errors, phonologically correct or orthographically correct) to discriminate. These groups were compared for literacy to test the hypothesis that they would vary in reading and spelling abilities. It was expected that reading and spelling errors would be highest in the group making phoneme segmentation errors and lowest in the orthographic response group. The groups were then compared for handedness to test the hypothesis that those children who made errors on the phoneme segmentation task would be less dextral than the other two groups.

Annett (1985) has proposed a genetic influence on speech processing so that a factor (the rs+ gene), as a by-product of it's function in lateralizing speech to the left hemisphere, influences handedness towards dextrality. Her suggestion of a balanced polymorphism predicts disadvantages for both homozygotes (rs-- and rs++). Evidence is increasing that the disadvantage for the rs-- genotype is a risk of problems with phonological processing but less evidence is available, to date, for the disadvantage for the rs++ homozygote. If phonological processing is associated with handedness so that poor ability is associated with reduced dextrality, and this involves a genetic influence, then the relatives of affected individuals should also vary in handedness. Individuals with poor phonological processing should not only be less dextral than other groups but they should also have more left handed relatives. Consequently, the final stage in this experiment was to compare the three groups for family handedness to test the hypothesis that the error group would have more left handed relatives than any other groups.

Method.

Participants - The sample included 391 (199 girls and 192 boys) schoolchildren with a mean age of 134.7 months and a std. dev. of 3.6 months (80% of the initial sample). Before any analysis which involved literacy 13 children with recognized special needs were excluded and one child with a history of severe arm injury was also excluded from analyses of handedness, as in the year 1 analyses. Three hundred and seventy seven children were left in the main sample.

Second year tests were presented individually to children who were selected on the basis of first year assessment. The design of the whole project was planned to be a complete sample of year 1, and then a process of searching for children with possible problems. These were to be children with problems of literacy, and also children with cognitive problems (e.g. poor phonology) generally believed to be associated with poor literacy. All children with scores which were at least one standard deviation below the mean in any cognitive test (word discrimination, word order memory, spelling, nonword spelling, visuo-spatial memory) in year one were selected for individual testing. As many controls from the same class as possible were also seen in that year. These criteria accomodated the requirements of all three researchers on the project.

Any additional children who had been seen in the first year and could be included in the second year were seen where possible as were any absentees and children who had changed to another school which was being visited.

Table 3.4 gives the means, standard deviations and ranges of the first and second year samples on these first year cognitive tests together with those of the children who were seen in the first year but not at second year follow up. Means, standard deviations and ranges for the holes measure of handedness are also given in table 3.4 but these were *not* used for selection of the second year sample.

Table 3.4: Mean Errors of Year 1 Cognitive Tests which were used for Year 2 Selection (samples cited are Yr 1, Yr 2 and children seen in Yr 1 but not in Yr 2)

	Yr 1 (n=459)		Yr 2 (n=377)		Yr 1 NOT 2 (n=82)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
1.2) Word Order Memory	4.22 (3.10)	15 (0-15)	4.33 (3.16)	15 (0-15)	4.21 (3.95)	15 (0-15)
1.3) Word Discrimination	4.64 (3.95)	30 (0-30)	4.72 (4.09)	30 (0-30)	4.39 (3.58)	30 (0-30)
1.4) Spelling	5.03 (3.18)	10 (0-10)	5.04 (3.25)	10 (0-10)	5.00 (2.93)	10 (0-10)
1.5) Non-word Spelling	1.32 (1.53)	6 (0-6)	1.49 (1.59)	6 (0-6)	1.44 (1.75)	6 (0-6)
1.6) Space(Visual Memory)	5.90 (2.67)	12 (0-12)	5.82 (2.65)	12 (0-12)	6.22 (2.71)	12 (0-12)
NOT used for year 2 selection						
1.1) R-L holes punched	54.53 (14.19)	90 (1-91)	54.97 (14.33)	90 (1-91)	55.93 (13.96)	67 (9-76)

Comparisons of the children from the first year sample who were seen at second year follow up and those who were not seen at follow up showed that they did not differ in their mean scores on the tasks which were used for selection i.e. word order, word discrimination, spelling, nonword spelling and visuo spatial task scores (t-test: word order memory t=1.11, df 476, p>0.1; word discrimination t= 0.84, df 474, p>0.1; spelling t= 0.29, df 476, p>0.1; nonword spelling t=0.54, df 476, p>0.1; and the visuo spatial task t=-1.38, df 476, p>0.1). Neither did the two groups differ for the first year measure of handedness (i.e. holes punched) although this task was not used for second year selection (right minus left hole punching t= -0.56, df 470, p>0.1). Chi-square comparisons for school and sex of children seen in the second year follow up and those not seen at follow up were also not statistically significant (school chi-sq. = 13.232, df 8, p >0.1; sex chi-sq. = 0.43023, df 1, p >0.1).

Family handedness data were collected in year 3 by distributing sets of hand preference questionnaires (see test 1.20 and appendix O) to all the families of children in the classes of the original cohort so this information was available for the majority of the sample.

Procedure. -

The tests used in the present analysis include the following:-

1.12: Phoneme Segmentation Task (phonology, second year)

The phoneme segmentation task was adapted (by PS) from Stuart (1990) and Bruce (1964). All the present stimuli were words and most correct responses were also designed to be words (although one possible word response in each list was unlikely to be known to 11 year old children).

The task was to listen to a word and repeat it with a sound missing. Copies of E's instructions are available in appendix H. Participants were instructed "I am going to say a word. I would like you to say the word back to me but with a sound missing - like this. If the word is jam and I ask you to say it without the /j/ you would say........?" Feedback was given to all subjects for the first two stimuli, but only continued to further training stimuli if necessary. This further training was only available for the first four stimuli (see 'Additional' sections on instructions in appendix H).

Target phonemes were in the initial position (eg. "fall - all"), the final position (eg. "pint - pine") or a central position (eg. "bind - bide"). The final six stimuli were designed so that different responses would be given depending upon the strategies used for making the deletion (after Stuart). Using a phonological strategy "find" resulted in the correct response "fine" but an orthographic strategy resulted in the response "fin".

(Stuart (1990) showed that good readers and spellers use an orthographic strategy, so either response was accepted as correct.) Responses which were neither phonological nor orthographic were scored as errors. (See preliminary analysis A for a partial replication of Stuart 1990 to confirm this decision.) Errors were scored for 10 items.

Two versions of the word list were used, during simultaneous testing, to prevent one child being influenced by another's responses. Both word lists, which were matched for frequency of words (both stimuli and responses) using Kucera & Francis (1967), can be found in appendix H.

Other tasks examined in relation to phoneme segmentation were:

1.4: Spelling Task (literacy, first year)
Ten words (see appendix C) were taken from year 10 of the Schonell spelling test B (Schonell & Schonell, 1952) and presented by dictation. The test was deliberately chosen to be difficult for 9-10 year olds to produce errors for analysis. The words were spoken once alone and then repeated in an appropriate sentence. The children were told 'If you are not sure how to spell them, it doesn't matter. Just do the best you can'. The task was presented in class as a group test and it was immediately followed by the nonword spelling task.

1.8: Peg Board Task Annett (1970a, 1992d) (laterality, second year)
A diagram of the wooden peg board can be found in appendix U. The aim was to move a row of 10 cylindrical wooden pegs, individually, from a row of holes at the top of the peg board to a row of holes at the bottom as fast as possible. Five trials were allowed for each hand, and the hands were alternated between each trial. The mean time for each hand was calculated and the following measure was used for most of the following analyses. The difference in time between the hands was expressed as a proportion of the sum of the means for each hand.

$$\text{R-L\% PEGS} = (((L-R)/(L+R))) \times 100).$$

1.9: Hand Preference (laterality, second year)

The hand used to perform each of the 12 movements on the Annett Hand Preference Questionaire (see appendix K) was observed and recorded using the tools and toys required (eg. pretend matches, table tennis bat, toy hammer and nail). Hand preference was classified individually, for each child, in the eight subgroups identified by Annett (1970a, revised to seven in 1985). The sub-groups are ordered for R-L hand skill (Annett, 1976; 1992d) and can be used as a parametric measure of hand preference. Class 5 was removed in the revision (1985) so classes 6-8 become 5-7 in statistical analyses which use sub-group handedness as a continuous variable.

1.11: Word Reading (literacy, second year)

The British Ability Scale (BAS, Elliot, Murray & Pearson, 1978) word reading test lists C and D were used as alternative forms (see appendix I for word lists).

1.20: Family Handedness. (laterality, third year)

Sets of hand preference questionnaires (AHPQ, see appendix K) were issued to children to take home for their parents and siblings to complete. Parents were requested to answer questions about their hand preferences for the 12 items of the Annett hand preference questionnaire. All available children from the original sample were given family handedness questionnaires, not just the year 3 sample.

Design of Analysis.

The main purpose of this analysis was to test the hypothesis that poor phonological segmentation is associated with a reduced bias to dextrality even when the task of phonological processing uses real words for stimuli. The analysis proceeded through stages as follows:

a) Are children who make more orthographic responses good readers and spellers (Stuart, 1990)? If this is true then it is appropriate to accept, as correct, orthographic as well as phonological responses to the task, even though instructions asked for *sounds* to be deleted. Consequently, 3 groups (with 0, 1-2 and 3+ orthographic responses to the phoneme segmentation task) were identified.

b) Are children with poor phonology (who make many errors on the phoneme segmentation task) to the left of the continuum of handedness when compared with those whose phonology is normal or good (who make phonological or orthographic responses)?

c) If groups of children are distinguished by their different responses to the phoneme segmentation task (incorrect, phonologically correct or orthographically correct) are there differences between the groups for literacy and laterality? Do they also differ in the handedness of their relatives?

Analysis a) Are Children who give Orthographic Responses Better Readers and Spellers than those who do not?

Results

The majority of the sample (81%) made no more than 1 error (mean 0.79, s.d. 1.39, range 10, min. 0, max. 10) provided that orthographic responses were accepted as correct.

Three groups were identified with different numbers of orthographic responses (0 responses - more than approximately 1 s.d. below the mean, 1-2 responses - approximately 1 s.d. below the mean to the mean, and 3+ responses - above the mean). Table 3.5 shows the mean orthographic responses and standard deviations of the three groups and the overall sample together with the range of the whole sample. The three groups were compared, by SPSS oneway ANOVA, for reading and spelling errors.

Table 3.5: Mean Orthographic Responses of the Whole Sample and Three Orthographic Groups (0, 1-2 and 3+ Orthographic Responses)

	Mean	S D	N
Whole Sample (range 6, min. 0, max. 6)	3.07	2.20	377
0 orthographic responses	0.00	0.00	72
1-2 orth. responses	1.48	0.50	93
3+ orthographic responses	4.82	1.08	212

Reading

Table 3.6 gives the mean reading errors (plus standard deviations) of the whole sample and the three groups, together with the range of the whole sample. Figure 3.3 illustrates the mean reading errors in the three groups with varying numbers of orthographic responses.

Table 3.6: Mean Reading Errors of the Whole Sample and Three Orthographic Groups (0, 1-2 and 3+ Orthographic Responses, ** Highly significant)

	Mean	SD	N
Whole Sample (range 14, min. 0, max. 14)	2.2	2.4	377
0 orthographic responses	4.1	3.5	72
1-2 orth. responses	2.3	2.1	93
3+ orthographic responses	1.5 **	1.4	212

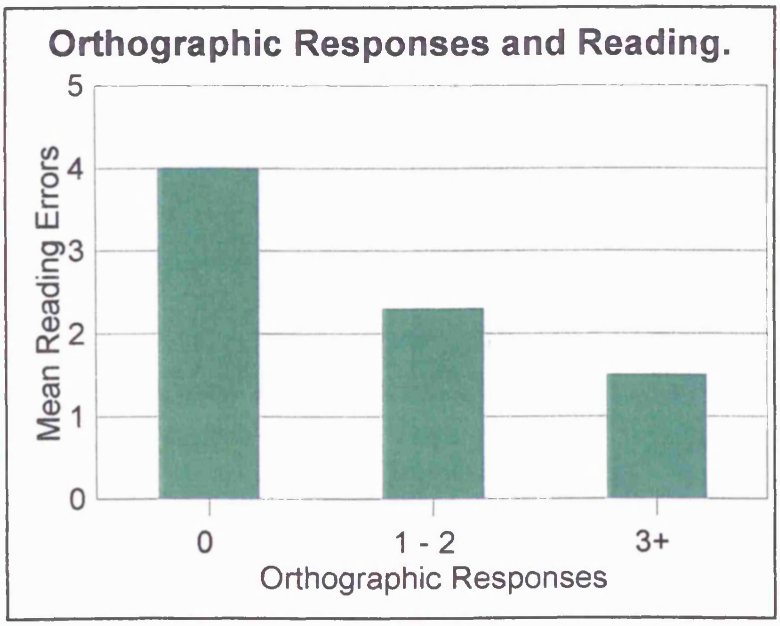

Figure 3.3: Reading errors of children with 0, 1-2 and 3+ orthographic responses.

The group making 0 orthographic responses had the highest number of reading errors with the group making 1-2 orthographic responses being intermediate and the group making 3+ orthographic responses making least ($F (2, 374)= 39.9$, $p=0.0001$). Unweighted and weighted linear terms were also highly significant (unweighted $F (2, 374) = 79.4$, $p = 0.0001$; weighted $F (2, 374)= 76.3$, $p = 0.0001$). Contrasts demonstrated that the group making no orthographic responses was highly statistically significantly different from both groups making some orthographic responses (contrasts *0 and 1-2 orthographic responses*: $t (374)= 5.33$, $p = 0.001$; *0 and 3+ orthographic:* $t (374)= -3.04$, $p = 0.003$) and the latter were significantly different from each other (*1-2 and 3+ orthographic responses*: $t (374)= 8.91$, $p=0.0001$).

Spelling

Table 3.7 gives the range of the whole sample together with mean spelling errors (plus standard deviations) of the whole sample and the three groups. Figure 3.4 illustrates the mean spelling errors for the three groups.

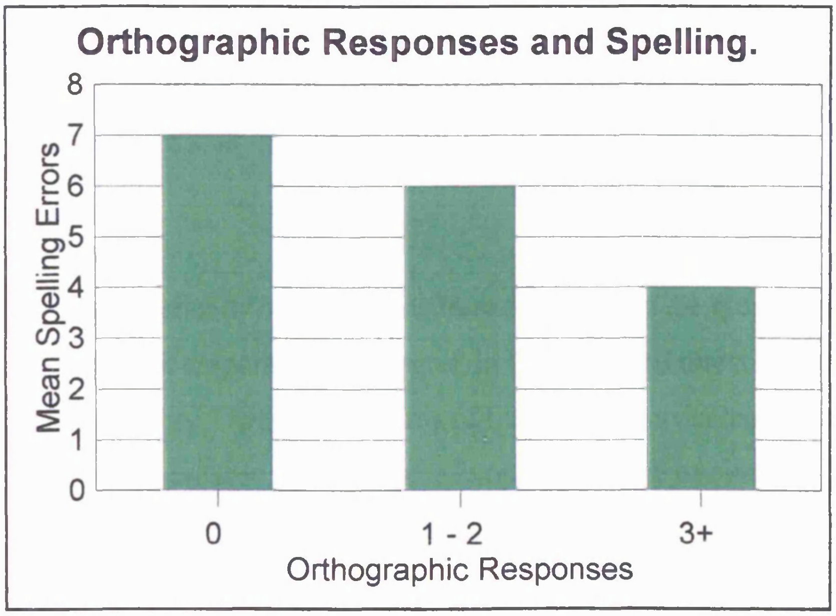

Figure 3.4: Spelling errors of children with 0, 1-2 and 3+ orthographic responses.

Table 3.7: Mean Spelling Errors of the Whole Sample and the Three Orthographic Groups (0, 1-2 and 3+ Orthographic Responses, ** highly significant)

	Mean	SD	N
Whole Sample (range 10, min. 0, max. 10)	5.0	3.2	377
0 orthographic responses	6.9	3.3	72
1-2 orth. responses	5.7	3.2	93
3+ orthographic responses	4.1	2.9	212
	**		

The group making no orthographic responses made more spelling errors than the goup making 1-2 which made more than the group making 3+. Differences between the groups were highly statistically significant ($F(2, 374) = 26.4$, $p = 0.0001$; unweighted linear term ($F(2, 374) = 46.3$, $p = 0.001$; weighted linear term $F(2, 374) = 52.4$, $p = 0.0001$). Again contrasts were also highly statistically significant between the group making 0 orthographic responses and both the groups making any orthographic responses (*0 and 1-2*: $t(374) = 2.48$, $p = 0.014$; *0 and 3+* : $t(374) = -4.34$, $p = 0.001$). Both groups making orthographic responses *(1-2 and 3+)* were also significantly different from each other ($t(374) = 6.80$, $p = 0.0001$).

The three goups differed significantly, in the predicted direction, on both measures of literacy. Reading and spelling errors decreased as orthographic responses to the segmentation task increased.

Discussion.

Highly statistically significant differences between the groups with varying numbers of orthographic responses were found, in the predicted direction, for both spelling and reading ability. On both measures of literacy, errors decreased as orthographic responses increased. These results support the body of evidence that orthography can influence phonological tasks (Seidenberg & Tannenhaus, 1979; Donnenwerth-Nolan, Tannenhaus & Seidenberg, 1981 and Ehri & Wilce, 1980) and Stuart's (1990) findings that better readers and spellers use an orthographic strategy for phoneme deletion tasks. The partial replication of Stuart confirms that in this phoneme segmentation task accepting orthographic responses as correct is necessary for the present purpose. If both phonological and orthographic responses were not accepted good readers and spellers would be penalized for using an efficient strategy. The instructions given to the child asked for a word to be repeated with a sound deleted so strictly adhering to instructions would require only a phonological response. Orthographic responses are arrived at by deleting a letter, not a sound, so strictly such a response should be counted as an error. However as the intention of the task was to measure ability at phoneme segmentation both phonological and orthographic responses were counted as correct. Consequently good readers and spellers were not penalized for having reached the stage of using orthography to influence a phonological task. In future more information would be gained from the test if, after a first response, each participant was asked if they could think of an alternative. This would indicate whether two routes were, or were not, available to the child.

Analysis b) Are children with Poor Phoneme Segmentation Ability Less Dextral than the Majority?

Having shown above that orthographic responses should be counted as correct, the main analysis for errors and laterality could proceed. The hypothesis was that children with poor phonology (who make neither phonological nor orthographic responses to the phoneme segmentation task) are to the left of the continuum of handedness when compared with those whose phonology is normal or good (and who make phonological or orthographic responses).

Results

The majority of the sample (81%) made not more than 1 error (mean 0.79, s.d. 1.39, range 10, min. 0, max. 10) so the criterion for a group with difficulties was set at 2+ errors (19% of the sample and approximately 1 s.d. above the mean). In this analysis groups with 0-1 (mean 0.229, s.d. 0.421) and 2+ segmentation errors (mean 3.053, s.d. 1.63) were compared for peg board hand skill by t-test and for writing hand by chi-square. The results were analysed both before and after selection to remove (i) those with particularly slow hand speeds and (ii) those with low Richmond vocabularies. Finally a full Bonferroni correction was used on both sets of analyses.

Peg Moving Hand Skill.

The whole sample had a mean pegboard hand skill of 3.8 (s.d. 4.5 and range 29.2, min. -9.4, max. 19.8). Table 3.8 gives the mean pegboard hand skill, standard deviations and numbers for each group both before and after selection and figure 3.5 illustrates the corresponding means for pegboard hand skill.

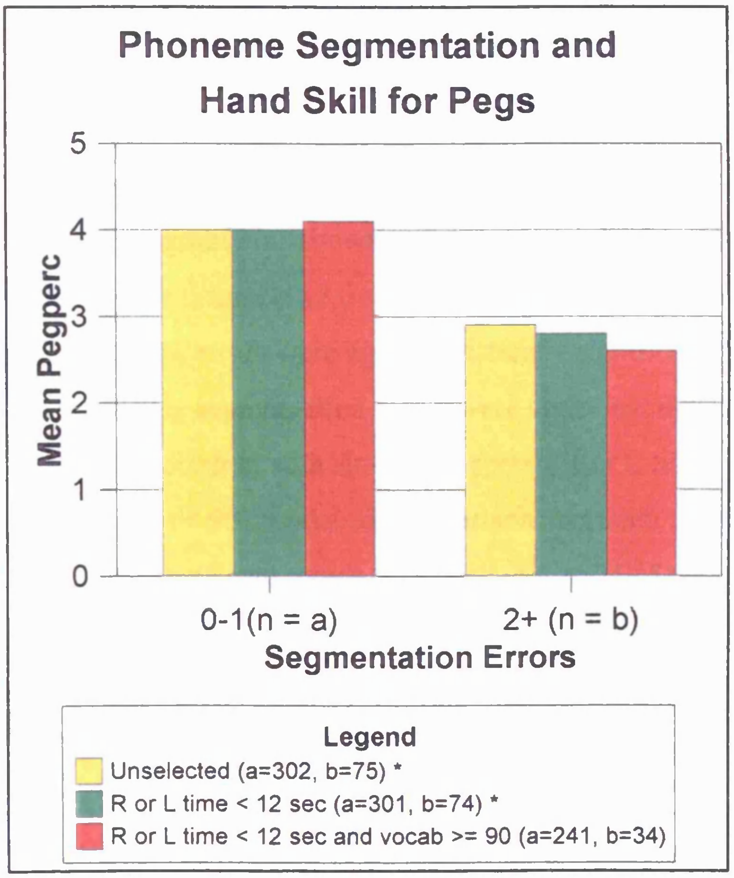

Figure 3.5: The mean hand skill for peg moving of children with few (0-1) and many (2+) phoneme segmentation errors. (*Unselected* - the whole sample, *R or L time < 12 secs.* - minus children with slow hand skill, *R or L time < 12 secs. and Vocab >= 90* - minus children with slow hand speed and poor vocabulary < 90.) * Stat. sig. contrast.

Table 3.8: Mean pegboard hand skill for each phoneme segmentation group both before and after selection (* statistically significant)

Selection	Group	Mean Pegperc	S. D.	N.
Unselected *	0-1 errors	4.0	4.4	302
	2+ errors	2.9	4.8	75
Minus R or L time	0-1 errors	4.0	4.4	301
> 12.0 secs *	2+ errors	2.8	4.8	74
Minus R or L time	0-1 errors	4.1	4.5	241
>12.0 sec & voc <90	2+ errors	2.6	5.0	34

Taking the whole sample, differences in mean peg board hand skill between groups with many and few phoneme segmentation errors were statistically significant (t (375)= 2.03; p= 0.043). Children making more phoneme segmentation errors were less dextral than those making few. Poor phoneme segmentation ability was associated with reduced dextrality (as shown in figure 3.5). After removing children with slow hand speeds (R or L time > 12.0 secs.) contrasts between groups with many and few segmentation errors were again statistically significant (t (373)= 2.01; p= 0.045). Those making many segmentation errors were again less dextral than those making few. Removing children with slow hand speed (R or L time > 12.0 secs.) and a low vocabulary (< 90) produced comparisons between the segmentation groups which were non-significant trends (t (273)=1.73; p=0.085). There was a trend for children making more phoneme segmentation errors to be less dextral than those making few despite a large reduction in size of the groups (as can be seen in table 3.7 and figure 3.5).

However a full Bonferroni correction for multiple comparisons required a significance level of 0.017 which was not reached by any of the present analyses.

Writing Hand.

Table 3.9 gives the number of left handed writers in the whole sample and the two groups both before and after selection and figure 3.6 shows the percentages of left writers in each group.

Table 3.9: Left handed writers in the whole sample and the two phoneme segmentation groups both before and after selection

Selection	Group	L. Writers	Percent.	N.
Unselected	Whole sample	43	9.4%	377
Unselected	0-1 errors	26	9%	302
	2+ errors	12	11.5%	75
Minus R or L time	0-1 errors	26	9%	301
> 12.0 secs	2+ errors	12	16%	74
Minus R or L time	0-1 errors	21	8.7%	241
>12.0 sec & voc <90 **	2+ errors	8	23.5%	34

** highly significant

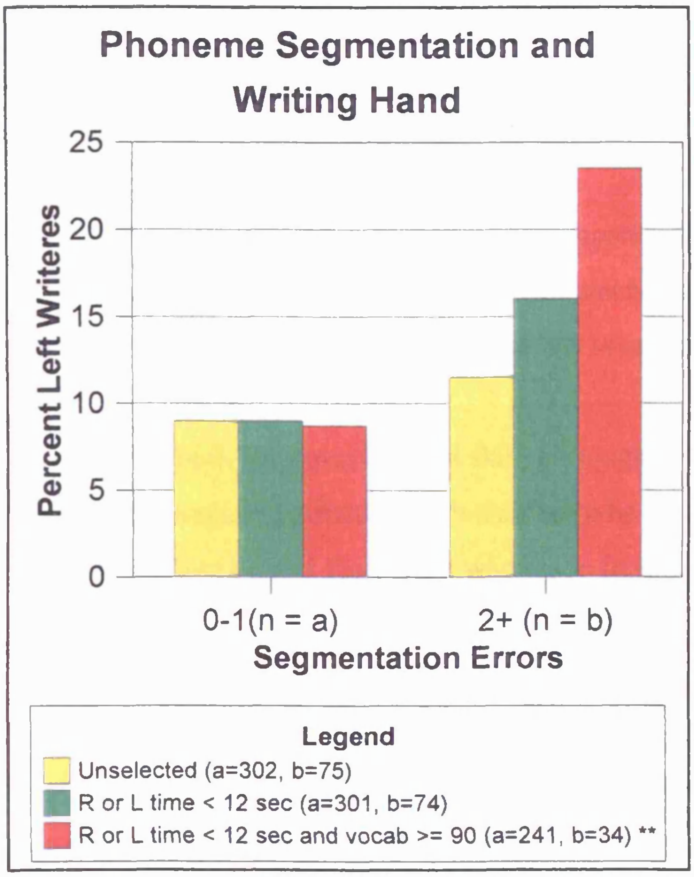

Figure 3.6: Percentages of left writers amongst children with few (0-1) and many (2+) phoneme segmentation errors. (*Unselected* - the whole sample, *Selected: R or L time < 12* secs. - minus children with slow hand skill, *Selected: R or L time < 12 secs. and Vocab >= 90* minus children with slow hand speed and poor vocabulary < 90.)
** Highly significant contrast.

Comparisons for writing hand in the whole sample found groups with many phoneme segmentation errors differed from those with few with a non-significant trend in the predicted direction (chi-sq. (1)= 3.62, p = 0.057). Eleven and a half percent of the children in the many error group were left writers compared with 9% of the children in the few error group. Those making more segmentation errors were less dextral than those making few. Removing two children with slow hand speeds (R or L time > 12.0 secs.) also resulted in a non-significant trend (chi-sq. (1) = 3.75, p = 0.053). The highest proportion of left writers (16%) was found in the many phoneme segmentation error group and the lowest proportion (9%) in the few errors group. Following exclusion of children with low vocabulary scores (less than 90) the group making many segmentation errors included 23.5% left writers while the few errors group included 8.7% (chi-sq. (1)= 6.93, p = 0.0085 highly statistically significant; Fisher's Exact p = 0.0153) as shown in figure 3.6.

A full Bonferroni correction for multiple comparisons required a significance level of 0.017 which was only reached in the present analyses after the final selection to remove those with slow hand speeds and low vocabularies.

Findings for both measures of hand skill, although not always statistically significant, were in the predicted direction with children who made more phoneme segmentation errors being less dextral than those who made fewer.

Discussion.

As predicted by the Annett RS theory children who made many phoneme segmentation errors were less dextral than those who did not although not all analyses were statistically significant. Trends were found for all measures of handedness and differences between groups increased after selection to remove those with slow hand skill and low scores on the Richmond vocabulary test. Again following a Bonferroni correction the analysis for writing hand, but not for hand skill, was still statistically significant after selection to remove children with slow hand skill and low vocabulary.

Figure 3.5 illustrates the increasing mean differences in hand skill between groups with selection and makes clear that reduced numbers after selection (from 74 to 34) are the probable cause of the lack of statistical significance after the final selection to remove individuals with poor general ability. Following this selection the group making many errors became less dextral but the group making few errors changed little in hand skill.

The analysis for writing hand showed non-significant trends for the group making many phoneme segmentation errors to include more left handed writers but after selection to remove those with slow hand speeds and low vocabularies highly significant differences in the expected direction were found. This was still statistically significant after applying a full Bonferroni correction for multiple analyses.

These results, using phoneme segmentation as a measure of phonological ability, supported those of the previous analysis for nonwords. As both stimuli and responses for the phoneme segmentation task were designed to be almost all real words it can confidently be asserted that the deficit examined in analysis one was not merely a difficulty with non-words but some form of phonological problem.

Support was provided here for the findings of Annett (1992a) that poor phonological processing was associated with reduced dextrality. Increasing differences between groups after selection, to remove those with poor vocabulary and slow hand speeds, again made it unlikely that the effects for handedness were due to "pathological handedness".

Analysis c) Do Children who make Different Responses to a Segmentation Task Differ for Literacy?

It could be argued that types of response to the segmentation task indicate different stages in the development of literacy. The ability to use an orthographic strategy which good readers and spellers have been found to possess could correspond with Frith's (1979) final stage of literacy development, the orthographic stage. Equally the ability to use a phonological strategy could correspond with the intermediate stage and the inability to use either could equate with the initial logographic stage (all discussed in the literature review). This led to the present analysis which used the segmentation task to explore the possibility that different responses to the task could reflect the attainment of different levels of literacy. Three groups were identified as follows:-

i) Error group; 2+ segmentation errors (more than approximately 1 s.d. above the mean, see page 78) in children who do not have an adequate grasp of phonology,

ii) phonological reponses; not more than 1 segmentation error (less than approximately 1 s.d. above the mean) and not more than 1 orthographically correct response (less than approximately 1 s.d. below the mean, see table 3.5) in children who had an adequate grasp of phonology but had not yet grasped orthographic processing,

iii) orthographic responses; not more than 1 segmention error (less than approximately 1 s.d. above the mean) and 2+ orthographically correct responses (more than approximately 1 s.d. below the mean) in children who were able to process both phonologically and orthographically.

The three groups were compared for reading and spelling ability using SPSS ANOVA. It was expected that those making mostly segmentation errors would also make most reading and spelling errors. Those making mainly phonological responses were expected to be intermediate and those making predominantly orthographic responses to the segmentation task were expected to make least reading and spelling errors.

Results

Details about the whole sample concerning means etc. of orthographic responses and reading, spelling and phoneme segmentation errrors have already been described in analysis (a) above (see tables 3.5, 3.6, 3.7 and page 78 respectively). When considering phonological responses to the phoneme segmentation task the whole group had a mean of 2.51 (s.d. 1.9, range 6, min. 0, max. 6).

Reading: Figure 3.7 illustrates the mean reading errors of the three groups with differing responses to the segmentation task and table 3.10 gives their corresponding standard deviations.

Table 3.10: Mean Reading Errors and Different Responses to a Phoneme Segmentation Task (highly significant).**

Group	Mean Reading Error	S D	N
Errors	4.8	3.3	75
Phonological responses	1.9	1.7	66
Orthographic responses	1.5	1.4	236
	**		

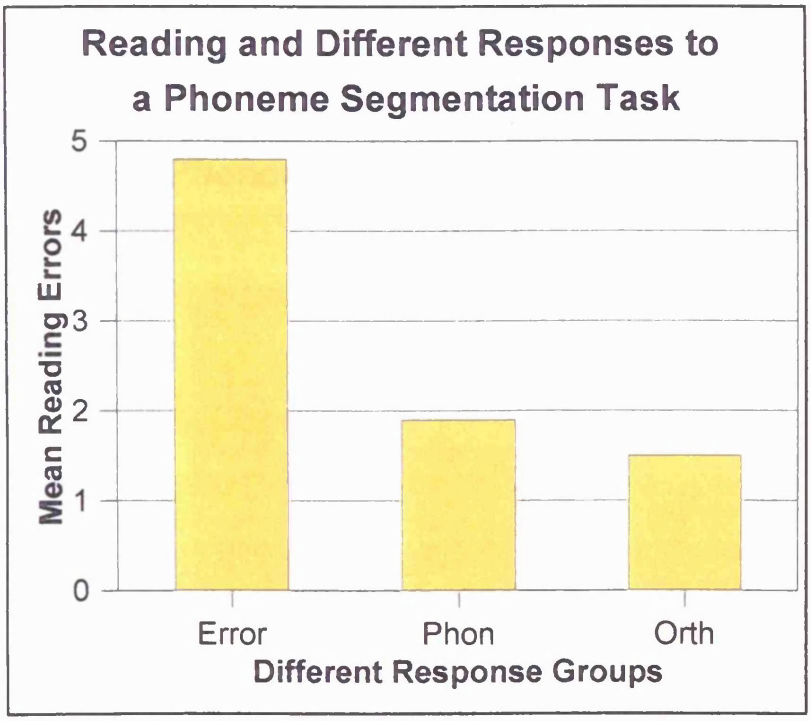

Figure 3.7:Reading errors of children with varying responses to the phoneme segmentation task (*Errors, Phon* - phonologically correct and *Orth* - orthographically correct).

Mean reading errors of the three groups differed in the predicted direction; decreasing from a maximum in the segmentation error group, through those making phonological responses, to a minimum in the orthographic response group (highly statistically significant, F (2, 375)= 80.38, p= 0.0001).

Spelling: Figure 3.8 illustrates the mean spelling errors of the three groups with different responses to the segmentation task and table 3.11 gives the corresponding standard deviations.

Table 3.11: Mean Spelling Errors and Different Responses to a Phoneme Segmentation Task (highly significant).**

Group	Mean Spelling Error	SD	N
Errors	8.4	2.2	75
Phonological responses	4.8	3.1	66
Orthographic responses	4.05	2.8	236
	**		

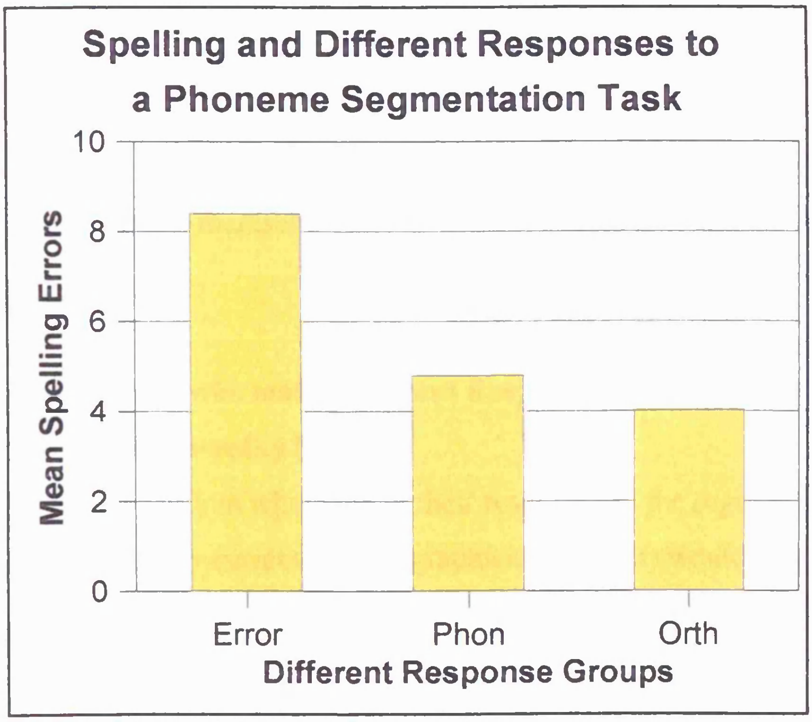

Figure 3.8:Spelling errors of children with varying responses to the phoneme segmentation task (*Errors, Phon* - phonologically correct and *Orth* - orthographically correct).

Mean spelling errors of the three groups differed in the predicted direction; decreasing from a maximum in the segmentation error group, through those making phonological responses, to a minimum in the orthographic response group (highly statistically significant F (2, 375)= 68.5, p= 0.0001).

Discussion

Children who made most orthographic responses to the phoneme segmentation task were found to make least reading and spelling errors while those who made mainly phonological responses were intermediate and those who made segmentation errors made most reading and spelling errors. This could reflect varying stages in the development of literacy as described by Frith (1979) but the bidirectional character of the segmentation /reading relationship (Barron, 1992) must also be borne in mind.

Different levels of segmentation (syllable, onset and rime) have already been described in the literature review as has the reciprocal nature of phonological awareness and reading ability. Barron (1992) suggested that each level of segmentation skills has a particular relationship to different aspects of reading development. Many studies have found that some levels of segmentation ability influence the acquisition of reading and some are then themselves influenced by reading practice (eg. Bertolson & De Gelder, 1989).

Do Children who make Different Responses to a Phoneme Segmentation task Differ for Laterality?

To test if children who vary in their responses to the segmentation task (incorrect, phonologically correct or orthographically correct) would also vary in handedness the same groups were compared for hand preference by chi-square and for hand skill by SPSS ANOVA.

Results

The sample as a whole had a mean of 2.51 (s.d. 1.9, range 6, min. 0, max. 6) phonological responses to the phoneme segmentation task. Details of the whole sample means for hand skill, segmentation errors, orthographic responses and percentages of left handed writers have already been described in the analysis above (see pages 82 and 78, table 3.5 and 3.9, respectively).

Hand Skill.

Figure 3.9 illustrates the mean peg moving hand skill of the three groups with differing responses to the phoneme segmentation task and table 3.12 gives the corresponding standard deviations.

Table 3.12: Mean Peg Moving Hand Skill and Different Responses to a Phoneme Segmentation Task (* statistically significant with a highly significant contrast between groups 1 and 3).

Group	Mean Pegperc	SD	N
1) Errors	2.3	4.8	75
2) Phonological responses	3.5	4.5	66
3) Orthographic responses	4.2 *	4.4	235

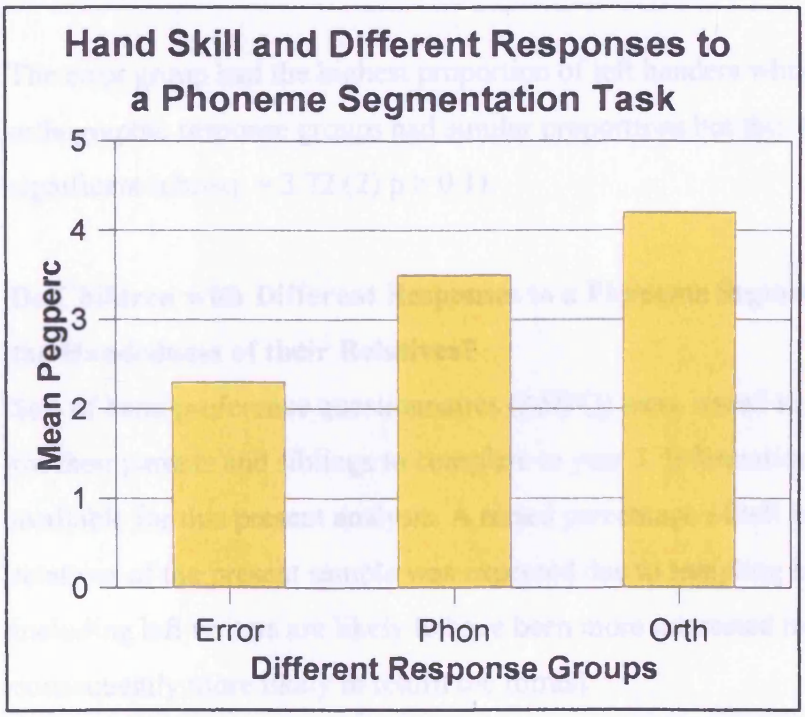

Figure 3.9: Mean hand skill for peg moving of children with differing responses to a phoneme segmentation task (*Errors*, *Phon* - phonologically correct and *Orth* - orthographically correct).

Comparisons of the three groups for hand skill were statistically significant, in the predicted direction (F (2, 375)= 2.78, p = 0.018). It can be seen from figure 3.9 that the error group was least dextral, the orthographic response group most dextral and those making phonological responses were intermediate. Highly significant contrasts existed between the group making errors and the orthographic response groups ($F (2, 209)= 3.61, p= 0.006$).

Writing Hand. Table 3.13 gives the percentage of left writers in each of the three groups with differing responses to the phoneme segmentation task.

Table 3.13: Percentages of Left Writers and Different Responses to a Phoneme Segmentation Task.

Group	Left Writers	(%)	N
Errors	12	(16%)	75
Phonological responses	5	(7.6%)	66
Orthographic responses	21	(8.9%)	236

The error group had the highest proportion of left handers while the phonological and orthographic response groups had similar proportions but this was not statistically significant (chi-sq. = 3.72 (2) $p > 0.1$).

Do Children with Different Responses to a Phoneme Segmentation task differ for the Handedness of their Relatives?

Sets of hand preference questionnaires (AHPQ) were issued to children to take home for their parents and siblings to complete in year 3. Information from these was available for this present analysis. A raised percentage of left handed writers amongst relatives of the present sample was expected due to sampling bias (i.e. families including left writers are likely to have been more interested in the research and consequently more likely to return the forms).

Results

In the whole sample 40 out of 235 (17%) relatives were left handed as were 32 out of 189 (17%) siblings.

To test if there is a genetic influence on phonological processing which would cause children who vary in their responses to the segmentation task (incorrect, phonologically correct or orthographically correct) to also vary in familial handedness the 3 groups were compared for relatives handedness (L vs R) by SPSS chi-square.

Figure 3.10 illustrates the percentage of left handed relatives in the three groups with differing responses to the phoneme segmentation task and table 3.14 gives the number and percentages of left handed relatives in each group.

Table 3.14: Left handed Relatives and Different Responses to a Segmentation Task

	L Handed Relatives (%)	N	L Handed Siblings	N
Errors	9 (24.3%)	37	8 (28.6%)	28
Phonological responses	2 (10%)	20	1 (6.3%)	16
Orthographic responses	29 (16.3%)	178	23 (15.9%)	145

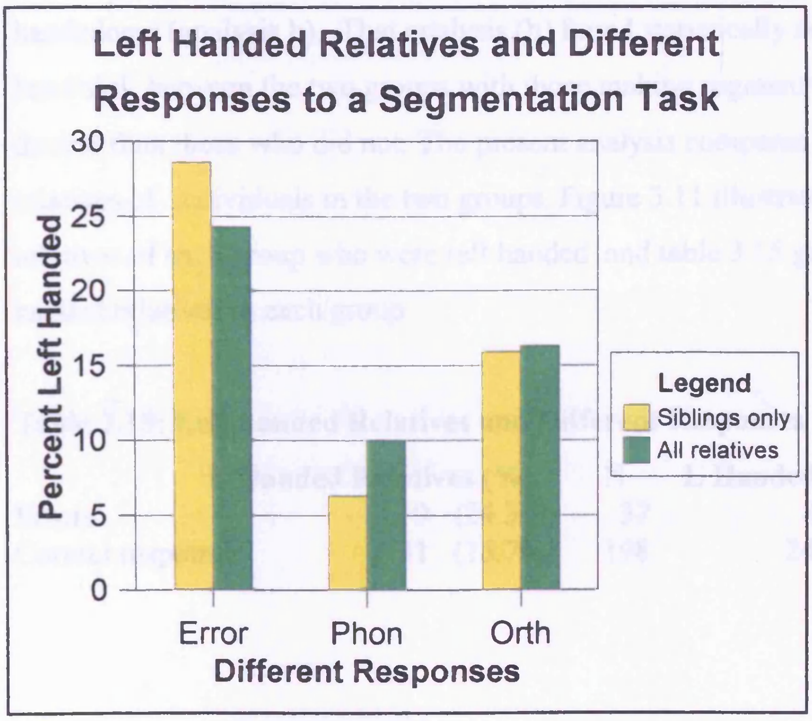

Figure 3.10: Percentages of left handed relatives of children with differing responses to a phoneme segmentation task (*Errors, Phon* - phonologically correct and *Orth* - orthographically correct).

The error group had more left handed relatives than both of the other two groups. Approximately 24% of the relatives in the error group were left handed as opposed to 10% in the phonological response group and 16% in the orthographic response group but chi-square was not statistically significant (chi-sq. (2)= 2.16, $p > 0.1$).

When siblings alone were examined the error group had more left handed siblings than the other two groups. Approximately 29% of the siblings of the error group were left handed in comparison with approximately 6% in the phonological response group and 16% in the orthographic response group. However chi-sq. was not statistically significant (chi-sq. (2)= 4.11, $p > 0.1$).

Combined phonological and orthographic response groups.

Combining the phonological and orthographic response groups resulted in a larger group which had minimal phonological problems. These two groups were now exactly the same as the two groups used in the first analysis of phoneme segmentation and handedness (analysis b). That analysis (b) found statistically significant differences in hand skill between the two groups with those making segmentation errors being less dextral than those who did not. The present analysis compared the handedness of relatives of individuals in the two groups. Figure 3.11 illustrates the percentage of relatives of each group who were left handed and table 3.15 gives the number of left handed relatives in each group.

Table 3.15: Left handed Relatives and Different Responses to a Segmentation Task

	L Handed Relatives (%)	N	L Handed Siblings	N
Errors	9 (24.3%)	37	8 (28.6%)	28
Correct responses	31 (15.7%)	198	24 (14.9%)	161

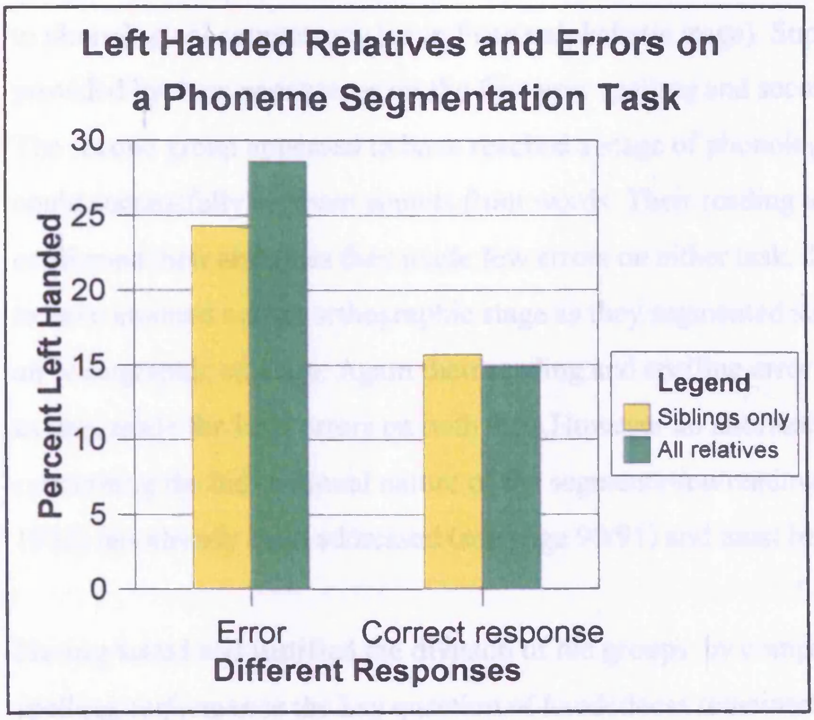

Figure 3.11: Percentages of left handed relatives of children who make errors on a phoneme segmentation task and those who do not (*Errors, Phon* - phonologically correct and *Orth* - orthographically correct).

Those children making segmentation errors had more left handed relatives (24.3%) than those who made phonological or orthographically correct responses (15.7%) but chi-square was not significant (chi-sq. (1)= 1.66, $p > 0.1$). When siblings alone were examined the error group had considerably more left handed siblings (28.6%) than the correct response group (14.9%) and chi-sq. was a non-significant trend (chi-sq.(1)=3.167, $p = 0.075$).

Discussion

This analysis used the different responses to a test of phoneme segmentation to divide participants into groups which could be argued to correspond with differing stages of literacy development. As expected reading and spelling errors were highest in the group making errors, intermediate in the phonological response group and lowest in the orthographic response group. The error group appeared to be unable to use either phonology or orthography (sounds or letters) to segment the sounds of words. This could imply that they were at a pre-phonological stage and had not yet broken through to phonological competency (as in Frith's alphabetic stage). Support for this was provided by their poor scores on the first year spelling and second year reading tests. The second group appeared to have reached a stage of phonological competency and could successfully segment sounds from words. Their reading and spelling scores confirmed their ability as they made few errors on either task. The third group appeared to have attained a final orthographic stage as they segmented sounds from words using an orthographic strategy. Again their reading and spelling error scores confirmed this as they made the least errors on both tests.However an alternative explanation concerning the bidirectional nature of the segmentation/reading relationship (Barron, 1992) has already been addressed (see page 90/91) and must be borne in mind.

Having tested and justified the division of the groups by comparing their reading and spelling performance the key question of handedness remained. On both measures of handedness, the error group was least shifted to the right, and the orthographic response group most shifted, with differences between the groups being in the predicted direction. The analyses for the pegs measure of hand skill, which is more sensitive than the holes measure and was available for all tests in the second year, was statistically significant but that for writing hand was not. However, phonological difficulties were of primary interest here so the phonological and orthographic response groups were combined to give one larger group with minimal phonological problems. An earlier analysis of peg moving hand skill in these two groups, with and without phonological problems, was statistically significant ($t(375) = 2.03$, $p=0.043$) and one of left and right handers was close to statistical significance (chi-sq. $(1) = 3.62$, $p= 0.057$).

It is necessary to acquire adequate skills in phonological processing before Frith's alphabetic stage can be reached. Consequently it can be assumed that children who have not broken through have deficits in phonological processing and Frith suggests that developmental phonological dyslexics are children who are arrested at this point. Frith's stages are a developmental progression in the growth of literacy. Handedness is not expected to change with literacy development but in a large sample of children of the same age those who have not yet broken through to the alphabetic stage are likely to include some with phonological deficits due to absence of the rs+ gene.

These analyses provide stronger support than before for the hypothesis that those children who are impeded in their attempts to break through to a phonological stage are more frequently found to be less shifted to the right for laterality. This is consistent with hypotheses of the RS theory but also with any adverse influence on development (i.e. minimal brain damage).

Although not statistically significant the analysis for relatives handedness demonstrated tentative support for a genetic influence when it was found that those who made errors on the phoneme segmentation task had considerably more left handed relatives than the other two groups. The phonological response group had the smallest number of left handed relatives as would be predicted by the RS theory because those who lack the influence of the rs+ gene (and hence lack the typical shift to dextrality in handedness) are expected to have phonological processing abilities which are influenced by chance. This genotype is expected to be at risk for phonological processing difficulties but despite this they would not be expected, in normal development, to have difficulties with breaking through to an orthographic stage, but only with attaining adequate phonological processing abilities. Consequently a reduced shift to dextrality is expected to be found in a group who make phoneme segmentation errors. However those in this genotype who by chance do not have difficulties with phonology are expected, in normal development, to have no difficulty in progressing to any stage of literacy development. An increased shift to dextrality is expected in a group which can make phonological responses as those with the typical shift are expected to pass through effortlessly to the phonologically capable group. It is likely that the group making orthographic responses would be intermediate in handedness as those with a reduced shift are not expected to have any additional difficulties with orthographic processing only the risk of phonological problems. This analysis was interpreted as demonstrating that in a sample of children of the same age, and similar education, those who have failed to break through to a stage of adequate phonological processing are likely to be less dextral than those who have succeeded and that this could be influenced by a genetic factor (the proposed rs+ gene).

General Discussion

The first analyses used nonword spelling as a measure of phonological processing and screened the entire sample for difficulties. Before selection for ability and at the lowest level of selection no statistically significant differences in handedness were found between the groups of children who made few or many nonword spelling errors. However, after selection to remove children with slow hand speeds, on the hole punching task, and poor Richmond vocabulary scores (less than 70) groups were found to be statistically significantly different for hand skill. As predicted, children making many errors on the nonword spelling task were less dextral than those making few. After a final selection, the analysis for hand skill was not statistically significant but examination of group sizes indicates that this was probably due to a severe reduction in numbers in the group with many errors (from 42 to 20). A similar selection (minus slow hand speed and vocabulary less than 90) for a measure of writing hand based on the first year holes punching task was highly statistically significant. Even following the use of a stricter criterion of a full Bonferroni correction the analysis for writing hand (but not hand skill) was still statistically significant after selection to remove children with slow hand skill and low vocabularies. This strengthening of the effect for handedness, after selection, makes it unlikely that cases of 'pathological' handedness are causing the association between phonological processing and handedness. This supported findings of Annett (1991a, 1992a) which demonstrated associations between poor phonology and reduced dextrality. These effects were found for specific phonological difficulties in a population which had no evidence for developmental pathology. However it was still not clear whether the effect could have been caused by a specific difficulty with nonwords. Consequently a further test of phonological processing, which used real words as stimuli and most responses, was used in the second year.

A preliminary analysis of the phoneme segmentation task supported the hypothesis that those who make more orthographic responses are better readers and spellers than those who make fewer orthographic responses. This supported Stuart's suggestion that good readers and spellers can use two routes for spelling and deletion tasks while poor spellers are forced to use the sub-lexical route. Consequently it was accepted that orthographic responses should be approved as correct responses to the task even though each participant was instructed that a "sound" should be removed from a word.

As expected children who made phoneme segmentation errors were less dextral than those who did not. Differences between groups were statistically significant, highly significant or non-significant trends for both measures of handedness both before selection and after selection to remove children with slow hand speeds. After selection to remove children with slow hand speeds and low vocabularies differences between groups for hand skill were non-significant trends and those for writing hand were highly statistically significant. Once more following the use of a full Bonferroni correction the analysis for writing hand (but not hand skill) was still statistically significant after selection to remove children with slow hand skill and low vocabularies. Again differences between groups increased after selection to remove those with low Richmond Vocabulary scores. This result, using a phoneme segmentation test which relied almost entirely on real words (for stimuli and responses), supported the hypothesis that a phonological difficulty was indeed being examined and not just a specific difficulty with nonwords. A majority of the original sample completed the segmentation task.

These results cast doubt on the ability of "pathological" theories to explain all variation in human handedness as in these analyses the pattern of results became stronger when children with slow hand skill and poor vocabularies were removed. Pathological explanations of handedness would predict that the effect of handedness would decrease with increasing intellectual ability but this was clearly not found here because the effect of handedness became stronger, not weaker,with selection for ability. The analyses found a relationship between phonology, vocabulary and handedness so that children who had poor segmentation skills but could nevertheless build a reasonable vocabulary had a reduced shift to dextrality. This convincingly demonstrated that the effect for handedness is not due to a disabled minority but can be found in the population as a whole. It adds to the existing evidence which supports the proposal of the RS theory that those at risk for deficits in phonological processing are found in the population as a whole and are likely to be less shifted to dextrality than the majority.

The Annett RS theory predicts that individuals who do not possess a copy of the rs+ gene are less biased to dextrality than those who do and are at risk for specific deficits in phonological processing. Children with phonological deficits but a good vocabulary (as reported in two experiments in this chapter) appear to be ideal candidates as their phonological deficit is not commensurate with other skills and they have been able to acquire a reasonable vocabulary despite their phonological difficulty .

The presence of at least one copy of the rs+ gene is expected to influence the lateralization of all aspects of speech processing to the left cerebral hemisphere so absence of this gene implies that this lateralization can be disturbed. Without the influence of the rs+ gene various aspects of speech processing could develop in different hemispheres or all could settle in the right or left hemisphere. Those children with poor phonology but a reasonable vocabulary, could be demonstrating the results of this variation. Their poor phonology could be the result of the atypical development of speech lateralization which is risked in the absence of the rs+ gene. Other abilities are expected to remain unaffected so these could be used to compensate and aid the acquisition of a good vocabulary.

Tentative support for the hypothesis that there could be a genetic influence upon phonological processing, as predicted by the RS theory, came from the examination of the handedness of the relatives of children who varied in their phoneme segmentation abilities. Those children with poor phonological processing were found to be least dextral and they had most left handed parents (not statistically significant) and siblings (a non-significant trend).

Several of these analyses provided evidence, consistent with previous research, that children with specific phonological problems are likely to lack the typical bias to dextrality. All results were in the predicted direction although some were not statistically significant. Two analyses showed that this effect for handedness increased after a selection for ability which provides evidence against a purely "pathological" explanation of handedness and in favour of a “specific disability hypothesis in those with otherwise normal development. The next chapter addresses the question raised by a further hypothesis of the RS Theory, that the shift to dextrality is absent in those with weak phonological processing and strongly present in those with good phonological processing.

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Chapter 4

Do Sub-types of Dyslexics Differ for Handedness?

The question of whether there are sub-types of poor readers (some with and some without poor phonology) that differ in handedness was examined, in the Wellcome sample, by Annett, Eglinton & Smythe (1996). This chapter extends the analysis by examining poor spellers in the sample distinguished for nonword spelling ability (as classified by Smythe in chapter 3). The Annett, Eglinton & Smythe analysis for reading is initially briefly reviewed for later comparison with the spelling analysis.

EXPERIMENT 3

Types of poor readers and handedness in children.

Introduction.

The RS theory of handedness (Annett, 1972; 1985) led to the hypothesis that individual differences in cognitive processing (found in large minorities of the population across all ability levels) may cause two different types of difficulty in the processes of learning to read (see figure 1.4). Several studies have reported evidence for two different types of dyslexia and these have been described in the literature review. Annett & Turner, 1974; Annett, 1985; Annett & Kilshaw, 1984; Annett & Manning, 1990a; Annett, Eglinton & Smythe, 1996; have explored reading development in the light of the RS theory finding evidence for the existence of two groups, with reading difficulties, which differ in their handedness (with either reduced dextrality or strong dextrality). These studies all supported the hypothesis that the development of reading is at risk at both ends of the continuum of hand skill.

It is important to note that handedness does not cause efficiency in cognitive functions or dyslexia. Nevertheless, the hypothesis that different types of dyslexia are associated with the two different homozygotes (rs-- and rs++) can be tested by comparing groups of dyslexics for hand preference and hand skill. The two genotypes cannot be distinguished yet but Annett, Eglinton & Smythe discriminated between dyslexics who did and did not have serious problems of phonological processing in order to test the hypothesis that these types differ, as expected, for the rs-- and rs++ genotypes. They examined the question of whether poor readers and spellers with varying phonological processing abilities also differed in handedness. It was expected that poor readers and spellers with poor phonological processing skills would be to the left of the continuum of handedness in comparison to poor readers and spellers with no phonological problem (see figure 1.4).

Method.

Participants – As described earlier, in chapter 2, these were 459 children from the main analysis. Before the analysis, in this section, 10 children were excluded for slow peg moving scores and 9 with matrices scores in the lowest 5% leaving 441 children.

Procedure. - Third year tests were administered individually to children who had been selected, as originally planned, as either having literacy problems or as controls, on the basis of first and second year assessment. Approximately 25% of the original sample was tested for a third time. The whole project was planned to be a complete sample of year 1, and then a process of searching for children with possible problems. These were to be children with problems of literacy, and children with cognitive problems (e.g. poor phonology) generally believed to be associated with poor literacy. Third year selections were made in the light of our analyses of the year 1 and 2 performances for reading, spelling (Eglinton) and nonword spelling/phoneme segmentation performance (Smythe).

Children were taken from class in pairs and tested individually, for approximately 20 minutes, by two experimenters usually Annett together with either Eglinton or Smythe (Annett, Eglinton & Smythe, 1996). In each pair, one child wore headphones for a computer task while the other was reading and doing other tasks.

The analysis will draw on the results of year 1 tests (hole punching, word order, spelling and nonword spelling) and year 2 tests (hand preference, peg board hand skill, phoneme segmentation, coloured progressive matrices and B.A.S. word reading). These have all been described in the previous chapter (except for word order which is described below).

First year tests were presented, as group tests, in class while second and third year tasks were all presented individually by Annett and either Eglinton or Smythe.

First Year Task.

1.2: Word Order Memory Task (phonology, Wordt = Wordc + Wordnc).

This is an auditory short-term memory span task that had been adapted for class presentation (Annett, 1992a). Seventy-two regular single syllable words of 3-4 letters (e.g. fin, tap, peg, hug) were presented in 18 sets of 4 on a printed sheet given to each child. These were selected as words that would be easy for 9-10 year olds, even poor readers, to discriminate. All stimuli were presented from a tape recorder. The children were instructed to

"Hold the pen in the air with your elbow on the desk while you listen to the words. Then as soon as the 4 words have been said, write down the numbers 1-4 over each word to show the order, and put your elbow on the desk while you listen to the next set."

Recall followed the presentation of each set of four words so that immediate recall of the order of auditory presentation was measured. Any response, which was not perfect recall for any set of four words, was scored as an error. Half of the word sets were confusable (wordc) eg. hot, pot, cot, lot and the other half non-confusable (wordnc) e.g. fin, tap, peg, hug. A full wordlist is available in appendix B.

Third Year Tests.

1.19: Nonword Reading (phonology)

Twelve nonwords from Psycholinguistic Assessments of Language Processing in Aphasia (PALPA, 36, Kay, Lesser & Coltheart, 1992), for example ked, pretch, glope, were read aloud by the participant. The two lists may be found in appendix N. They were balanced for nonword length and consisted of three each of 3, 4, 5 and 6 letter nonwords. One error was scored for each illegal nonword pronunciation.

1.15: Reading (literacy)

The Schonell Graded Word Reading (GWR) task was presented to confirm the accuracy of the year 2 B.A.S. reading test (see appendix I for word list). The child tested in parallel was fully occupied in performing a computer based experiment which required the wearing of headphones and was conducted at the other end of the room so that eavesdropping on words was impossible. The task was scored for reading age (RA) and reading quotient (RQ) calculated by the conventional formula of RQ = (RA/CA) x100 where CA is chronological age.

1.16: Spelling (literacy)

The same ten words (see appendix C), taken from year 10 of the Schonell spelling test B (Schonell & Schonell, 1952), used in year 1 were presented again. This was intended to check the reliability of the spelling classification and to assess progress.

1.20: Family Handedness. (laterality)

Family handedness was established from AHP questionnaires. Details of the task can be found in chapter 3 and appendix O.

Classification of the Sample and Exclusions

The classifications of the sample are illustrated in figure 4.1, taken from Annett, Eglinton & Smythe, 1996. The initial classification was for three groups of varying reading and spelling ability. The classification of poor reading was by both regression criteria and absolute levels of reading ability. The poor reading group were the lowest 10% of the sample, there was a similar sized poor spelling but not poor reading group (reading errors not more than 6 plus spelling errors not less than 9) and a control group (the remainder of the sample). Whole sample means etc. for reading and spelling ability were described in the previous chapter and those for age may be found in chapter 2.

A measure of reading ability dependent upon age and non-verbal intelligence was calculated by regressing CPM and age at time of testing on reading score (the 2nd year B.A.S. test) and details can be found in table 4.1. Less than 1% of variance (R^2=0.00921) on the reading test scores could be accounted for in terms of variance in age and less than 10% (R^2 = 0.09567) in terms of age and CPM (non-verbal intelligence).

Table 4.1: Regression analysis of CPM and age on BAS reading score (all 2nd year)

Variable	R^2	df	F	p	B	SE B	Beta	T	p
Age	0.00921	1, 375	3.49	0.063	-0.63	0.034	-0.096	-1.87	0.063
Age	0.09567	2, 374	19.78	0.001	–0.39	0.032	-0.061	-1.23	0.218
CPM					0.17	0.028	0.296	5.98	0.001

Children with a residual standardized regression score of 1.3 or more were not reading at the level that would be expected from their age and non-verbal intelligence. The poor reading group was completed by adding those children with a reading quotient of not more than 80 (approx. 1 s.d. below the mean). Reading quotient is a measure of reading age which was calculated from the third year Schonell test of reading. All children who were not seen in years 2 and 3 were included in the control group, as they were not seen in year 3 because their performance at reading and spelling was adequate.

Further Exclusions: In the next classification 10 children with very slow speeds on one hand (2.5 s.d. below the mean) and 9 with very low non-verbal intelligence scores (CPM not less than 18 errors and the lowest 5% of the scale) were removed from the total sample. This was done to withdraw cases that might be suspected of pathology whether or not they were poor readers or spellers by the criteria above. No child was slow with both hands.

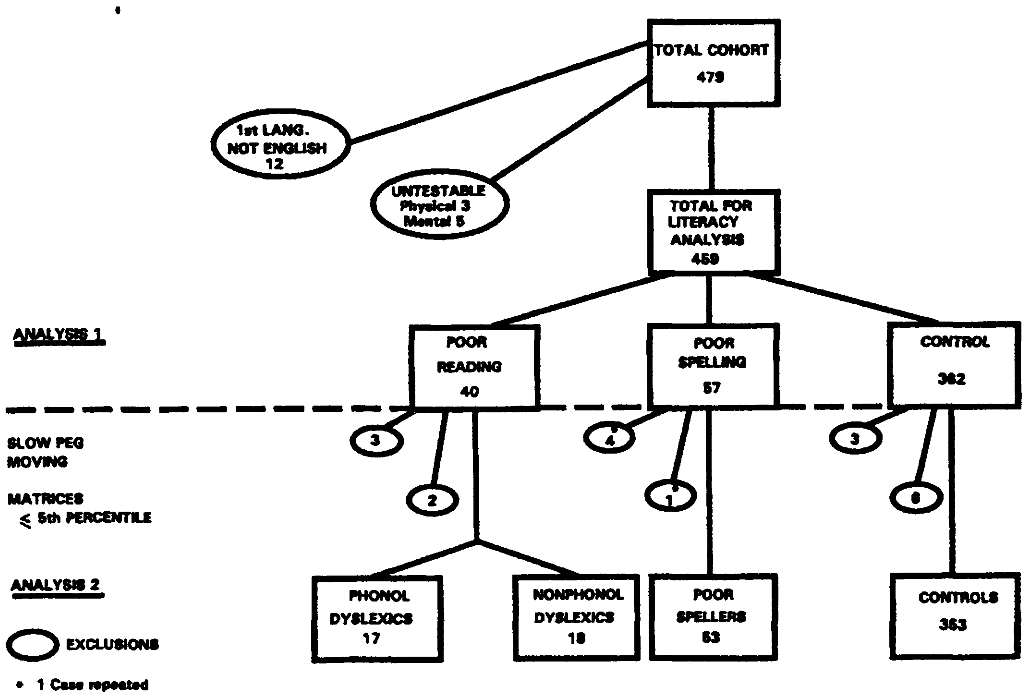

Figure 4.1: Classifications of the sample and Exclusions

Further Classification: The poor reading group were classified as 'phonols' (with a phonological problem) and 'nonphonols' (with no phonological problem but with some other unspecified difficulty). The dyslexia group was classified by their performance on three tests designed to assess phonological processing (phoneme segmentation, nonword reading and word order). The combination of these 3 test results gave a strong assessment of phonological difficulty. Subjects were judged as having a phonological problem if their performance was poor on at least two out of three of these tests (1 std. dev. above the mean for errors).

The main analysis tested the hypothesis that dyslexics with poor phonology (phonols) lack the typical bias to dextrality and other dyslexics (non-phonols) are strongly dextral. It was predicted that the proportion of left-handers would be higher amongst phonol dyslexics than amongst non-phonols. Comparisons for handedness were made by SPSS Chi-sq. (with corrections for continuity or Fisher exact as appropriate) and SPSS oneway anova.

Results.

Left Writers: In the whole sample 10.4% (46) were left writers and table 4.2 shows the percentage of left-writers in each of the four literacy groups.

Table 4.2: Left-writers in Literacy Groups.

	Phonols	Poor Spellers	Controls	Non-phonols
L handers (%)	5 (29.4%)	7 (13.6%)	34 (9.7%)	0 (0%)
N	17	53	353	18

Percentages of left writers differed significantly between groups (chi-sq. = 9.258 (df 3) p=0.026). Phonols were statistically significantly less dextral than nonphonols (chi-sq. = 4.008, df 1, p=0.045; Fisher exact p = 0.020) and controls (chi-sq. = 4.689, df 1, p=0.030). Results were in the predicted direction and many were statistically significant.

Hand Preference Sub-group and Hand skill: The four literacy groups differed for hand preference sub-group, as defined by Annett, 1985, (F ratio = 3.013, df 3, 405, p=0.030). They also differed for hand skill for R-L% holes (p = 0.022) and R-L% pegs. Statistically significant contrasts demonstrated phonols to be less dextral than non-phonols (hand preference p=0.010, R-L% holes p=0.045, R-L% pegs p=0.016), poor spellers (p=0.006, R-L% pegs p=0.014) and controls (hand preference p=0.005, R-L% holes p=0.025, R-L% pegs p=0.006).

Figure 4.2 illustrates the distributions of sub-group hand preference in the three main groups (both types of dyslexic and controls). Phonol percentages were much lower than non-phonol percentages in the most dextral hand preference groups (1-3). In contrast phonol percentages were much higher than non-phonol percentages in the less dextral groups (4-8).

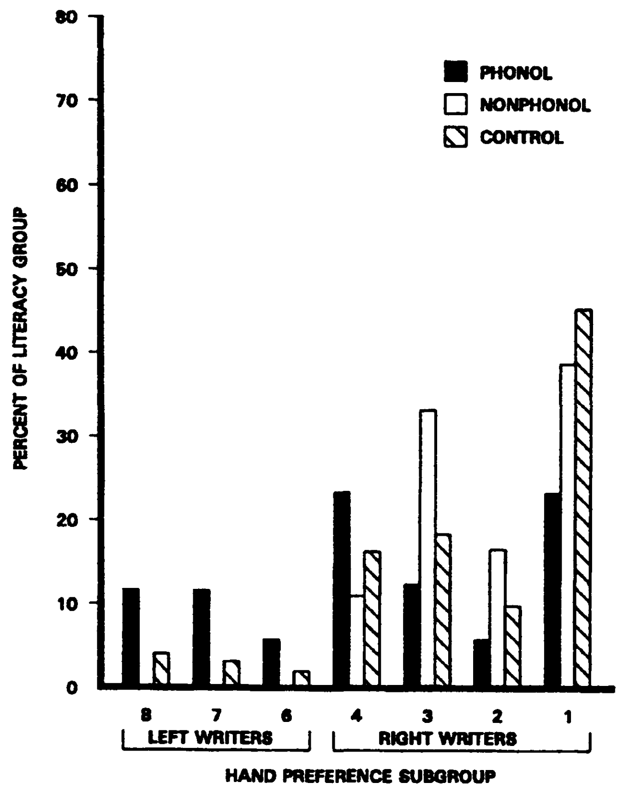

Figure 4.2: The Distribution of Hand Preference Sub-group in two types of Dyslexic and Controls.

Discussion.

When poor readers were divided into those with and without phonological problems they varied in accordance with expectations of the RS theory. 'Phonols' were the least dextral of all groups while 'non-phonols' were most dextral. This was found over three measures of handedness (holes, pegs and hand preference sub-groups) and contrasts between 'phonols' and 'non-phonols' and 'phonols' and controls were all statistically significant.

Hand skill means for phonols were close to 0, especially in peg moving, as expected for a group that lacks bias to dextrality. Figure 4.2 illustrates the distribution of sub-group handedness in both dyslexic groups and controls. Unambiguous differences were found between hand preference sub-groups for the percentages of phonols and non-phonols that they include. Phonol percentages were much lower than non-phonol percentages in the most dextral hand preference groups (1-3). In contrast phonol percentages were much higher than non-phonol percentages in the less dextral groups (4-8). Nonphonols were obviously shifted to the right and phonols were randomly distributed over all the hand preference groups as would be expected for a group with little bias to dextrality.

These analyses showed differences between 'phonols' and controls which were in the predicted direction and statistically significant. Those between 'nonphonols' and controls were not statistically significant but showed strong trends in some analyses and were always in the predicted direction.

EXPERIMENT 4

Types of poor spellers and handedness in children.

This section makes a new analysis, of the contrast between children with poor versus good phonology, based on a criterion of nonword spelling in year one. The new analysis examined handedness in poor spellers independently of dyslexic poor readers. It resembled the Annett, Eglinton & Smythe analysis above but differed in certain details as poor nonword spellers were compared with poor spellers.

Participants

Only children seen in year 3 were included and none were excluded because of slow peg times. Some 25% of the initial sample were seen at third year follow up. These included all children identified as having specific problems of reading who were still present in school, as many children as possible with specific problems of spelling and controls from the same classes. Overall the sample (n = 125) included 16 (12.8%) left handed writers and table 4.3 gives the means, standard deviations and ranges of the whole sample for the first year tests of spelling and nonword spelling errors and the second year tests of BAS reading errors.

Table 4.3: Mean Spelling, Nonword Spelling and B.A.S. Reading Errors

Variable	Mean	Std. Dev.	Range	Min-Max.
Spelling errors (year 1)	7.00	3.27	10	0 - 10
Nonword spelling errors (year 1)	2.36	1.92	6	0 - 6
BAS reading errors (year 2)	3.31	3.10	14	0 - 14

Classification

Poor word spellers were selected as those making 8+ spelling errors in year 1 (above the mean and not 9+ as in Annett, Eglinton and Smythe above) while poor nonword spellers made 4+ errors in year 1 (approximately 1 s.d. above the mean). Poor nonword spellers were extracted from the poor spellers and controls but kept distinct from dyslexics. Controls made less than 6 reading errors, in year 2, (more than 1 sd below the mean) and less than 8 spelling (mean and below) and 4 nonword spelling errors, in year 1 (more than 1 sd below the mean). This resulted in the following five groups:-

- *Ph. Dys* - phonol dyslexics (n = 19),
- *Non-Ph. Dys* - non-phonol dyslexics (n =16),
- *Poor. Sp.* - poor spellers with few nonword spelling errors (n = 33),
- *Poor Ph. Sp.* - poor nonword spellers (n =11),
- *C.* - controls (n = 46).

This analysis was conducted with the intention of assessing the handedness of two types of poor spellers (with and without poor phonology) independently from dyslexic readers. It was expected that poor spellers who could *not* spell nonwords would include more left writers and be less dextral, for hand skill, than both poor spellers who could spell nonwords and controls. Comparisons for handedness were made by SPSS Chi-sq. and SPSS oneway anova and contrasts where appropriate were Least Significant Difference.

Results.

Hand Skill: The whole sample had a mean peg moving percent of 4.01 (s.d. 4.6, range = -7.8 to 18.2, n = 125). The mean peg moving percent (R-L%) of each literacy group is shown in figure 4.3 and corresponding standard deviations etc. are to be found in table 4.4

Table 4.4: Mean Peg Moving Hand Skill of the spelling groups classified above.

Spelling Group	N	Mean R-L%	SD
1 Phonological dyslexics	19	1.93	5.49
2 Non-phonological dyslexics	16	4.32	4.23
3 Poor spellers (not nonwords)	33	5.09	4.39
4 Poor non-word spellers	11	-1.13	5.09
5 Controls	46	3.52	4.67

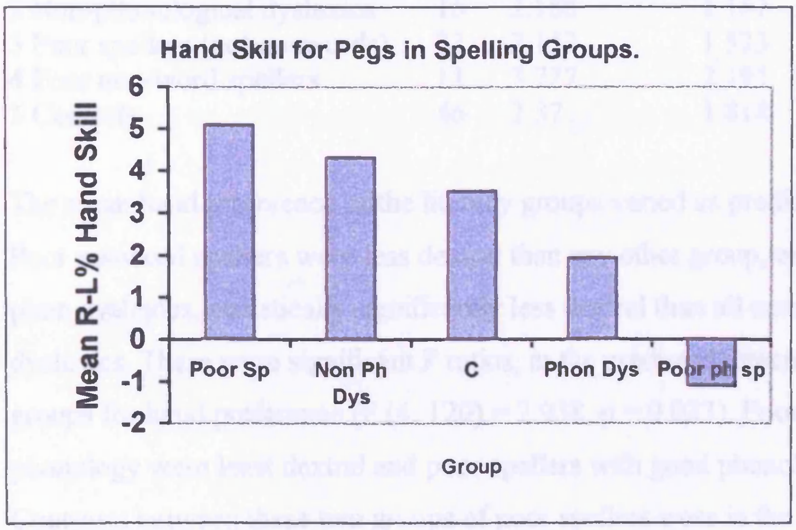

Figure 4.3: R-L% hand skill, for peg moving, in the spelling groups classified above.

Poor nonword spellers were less dextral than any other group controls, poor spellers, non-phon dyslexics, and statistically significantly less than all except phonological dyslexics. In addition poor spellers who could spell nonwords were more dextral than non-phonol dyslexics.

Hand skill for peg moving F ratios between the spelling groups were statistically highly significant (F (4, 120) = 4.21, p = 0.003) in the predicted direction. Poor spellers with poor phonology were least dextral and poor spellers with good phonology most dextral.

Contrasts between these two groups of poor spellers were in the predicted direction and statistically highly significant (t (42) = 3.95; p= 0.001).

Hand Preference: The whole sample had a mean hand preference of 2.55 (s.d. 1.78, range 7, min. 1, max. 7 [8 sub-groups minus sub-group 5, see chapter 1 and chapter 2 for details], n = 125) and table 4.5 shows the mean hand preference of the literacy groups. Hand preference group 1 are consistently right in hand preference while higher means indicate greater sinistrality.

Table 4.5: Mean hand preference in the spelling groups classified above.

Spelling Group	N	Mean Hpref	SD
1 Phonological dyslexics	19	3.316	1.945
2 Non-phonological dyslexics	16	2.188	1.167
3 Poor spellers (not nonwords)	33	2.152	1.523
4 Poor non-word spellers	11	3.727	2.195
5 Controls	46	2.37	1.818

The mean hand preference of the literacy groups varied as predicted by the RS Theory. Poor nonword spellers were less dextral than any other group, controls, poor spellers, non-phon dyslexics, statistically significantly less dextral than all except phonological dyslexics. There were significant F ratios, in the predicted direction, between the spelling groups for hand preference (F (4, 120) = 2.938, p = 0.023). Poor spellers with poor phonology were least dextral and poor spellers with good phonology most dextral. Contrasts between these two groups of poor spellers were in the predicted direction and statistically significant (t (42) = -2.58; p= 0.014).

Left Writers: When considering left handed writers the whole sample included 12.8% (16 from 125). The percentage of left writers in each group is shown in figure 4.4.

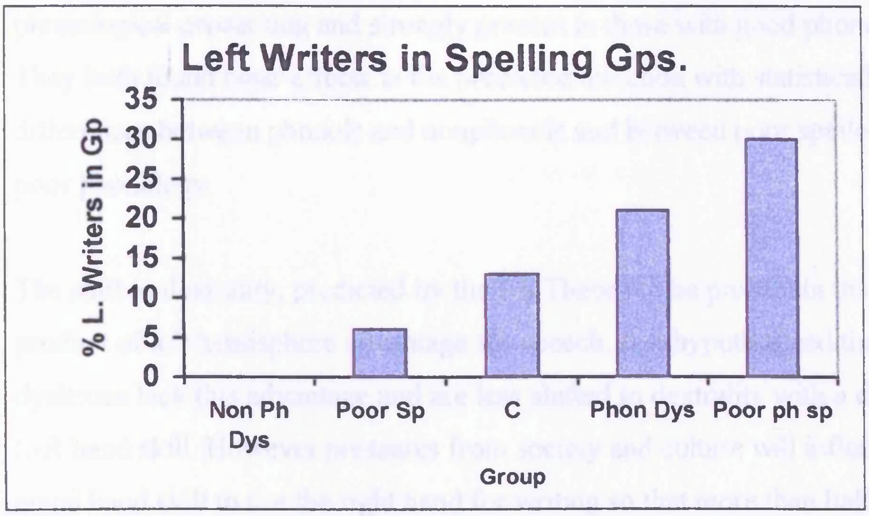

Figure 4.4: Percentage of left writers in spelling groups classified above.

Few left writers were found amongst the poor spellers who could spell nonwords (6%, 2 out of 33) or the non-phonol dyslexics (0%, 0 out of 16), many were found in the poor nonword spelling (36%, 4 out of 11) and phonol dyslexic (21%, 4 out of 19) groups while controls were intermediate (13%, 6 out of 46). A comparison for numbers of left-handed writers in the spelling groups was statistically significant (chi-sq. (4)=10.325, p = 0.035).

Discussion

On both measures of handedness (hand skill for peg moving and writing hand) poor spellers with poor phonological processing skills were to the left in comparison to poor spellers with no phonological problem. Only children seen in year 3 were included in the present analysis and none were excluded because of slow peg times. These findings replicated those of Annett, Eglinton & Smythe (1996) for poor readers, in poor spellers independent from dyslexic readers. Differences were demonstrated, between poor spellers who can spell nonwords and those who cannot, which are even stronger than those shown between phonol and non-phonol dyslexics by Annett, Eglinton & Smythe (1996). All results in this spelling analysis were in the predicted direction. These results strengthen and extend the Annett, Eglinton & Smythe work.

General Discussion.

These two studies have classified poor readers and poor spellers for phonological processing to test the hypothesis that the shift to dextrality is absent in those with weak phonological processing and strongly present in those with good phonological processing. They both found clear effects in the predicted direction with statistically significant differences between phonols and nonphonols and between poor spellers with good and poor phonology.

The shift to dextrality, predicted by the RS Theory to be present in the majority, is a by-product of left hemisphere advantage for speech. It is hypothesized that phonological dyslexics lack this advantage and are less shifted to dextrality with a chance distribution of L-R hand skill. However pressures from society and culture will influence many with equal hand skill to use the right hand for writing so that more than half of these will be right-handers. When these are added to the predicted dyslexics who are strongly dextral due to the possession of two copies of the rs+ gene (Annett, 1985) then it explains why there is a raised number of left handers amongst dyslexics although most dyslexics are right handed (Zangwill, 1962).

The suggestion that some dyslexics do not have the typical cerebral asymmetry has been supported by several studies using physiological measurements. Galaburda (1994) has described evidence from autopsy studies of dyslexics and support for cerebral symmetry in dyslexics but not controls, comes from an increasing number of studies (Kushch et al., 1993; Hynd et al., 1995). Reduced asymmetry in phonological dyslexics has been reported from electrophysiological (Flynn & Boder, 1991, review) and MRI studies (Larsen, Hoien, Lundberg & Odegaard, 1990). In addition, atypical cerebral asymmetries in speech areas have been demonstrated to be associated with atypical handedness in MRI studies (Habib, Robichon, Levrier, Khalil & Salamon, 1995). A strong bias to the typical right ear advantage, in dichotic listening, has been found in dyslexics with visuo-spatial problems while the distribution of those with language difficulties was bimodal (Cohen, Hynd & Hughdahl, 1992). The mounting physiological evidence for atypical cerebral symmetry in dyslexics, but not controls, supports predictions of the RS theory for an absence of shift in phonological dyslexics.

Having clearly demonstrated that poor readers (Annett, Eglinton & Smythe, 1996) and poor spellers with phonological problems are less dextral than those without such difficulties the next chapter of this thesis moves on to consider the varying aspects of phonological processing.

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Chapter 5

Two Investigations of Components of Phonological Processing in Children.

This chapter describes two factor analyses on tests given to the Wellcome school sample. The first includes tasks given in years 1 and 2 while the second includes tasks from years 1, 2 and 3. Year 1 tests alone produced only one factor which consequently could not be rotated so analysis begins with year 2. The resulting factors were examined in the light of the RS Theory.

EXPERIMENT 5

Components of phonological processing in children (factors in yrs 1+2).

Introduction.

It was noted in the literature review that many researchers (eg. Snowling, 1992; Frith, 1992; Goswami and Bryant, 1991) argued that phonological processing consisted of several different components. Frith proposed that problems which prevented children from breaking through to the alphabetic stage could stem from difficulties with phonological awareness, phoneme segmentation or output phonology. She suggested that reading and spelling do not develop in phase with each other so that a child can be in one phase for reading and another for spelling. Arguing that logographic skills first emerge in reading and alphabetic skills first emerge in spelling she proposed that normal children initially learn and use grapheme-phoneme-conversion skills for spelling (writing) and only later transfer them to reading.

Snowling argued that likely candidates for the individual components of phonological processing were the perception of phonemes, the separation of phonemes, their manipulation, their storage in memory during manipulation, the restringing of phonemes in new forms and the setting up of new codes for articulation. Different tasks which involve phonological processing are expected to use combinations of some or all of these components and Snowling suggested that different deficits in phonological processing could result from difficulties with any one or any combination of these procedures. She argued that difficulties in different phonological processes could be responsible for individual differences in reading and spelling performance even in the homogenous group of phonological dyslexics. Members of the group would be similar in that they had not achieved good alphabetic skills but different as their problems arise from different phonological processes.

Some studies (see chapter 1, part 2) have attempted to isolate individual phonological processes (usually phonological memory or production) but in doing so they have ignored other phonological processes. Many studies have also used small numbers of subjects. Others have begun by excluding children who did not perceive the difference between two similar words. It seemed possible that these practices could have biased the studies so that they began by filtering out some relevant component of phonological processing which may be crucial in the development of reading or spelling skills.

If phonological processing consists of various different component processes then some or all of these (which may or may not be essential for literacy and/or related to handedness) could be separated out by factor analysis. When work on this thesis began, there had been no attempts to separate and identify these various aspects of phonological processing using a representative sample from a normal population. Consequently the first question for investigation in this chapter was to see what components of phonological processing could be identified in schoolchildren. Following this the next aim was to test the relevance of these factors as processes important for the development of literacy . This was done by testing their ability to predict competence in reading and spelling abilities. A further aim of this chapter was to test if any factors, which were distinguished, were also associated with handedness in order to investigate the question of what, if any, components of phonological processing are relevant to individual differences for patterns of cerebral dominance.

In order to contrast a 'phonological' factor with an anticipated non-verbal or visuo-spatial factor three non-verbal tests were also included in the factor analysis. It is predicted by the RS theory that a dissociation exists between phonological and visual processing deficits and that this is related to laterality. A specific deficit in phonological processing is expected to be associated with reduced dextrality while a specific deficit in visual processing is expected to be associated with strong dextrality. This led to a fourth aim which was to contrast the handedness of groups who were good at one factor but not the other with the expectation that there would be a similar dissociation.

Both analyses proceeded through several stages as follows:

a) Can phonological factors be identified in schoolchildren?

b) Are the factors validated by an association with reading and spelling ability?

c) Are the factors associated with handedness?

To test these hypotheses, findings from the several years of testing were entered into three factor analyses, one for each year. Analyses reported here begin in year 2 because only one factor of verbal processing, which could not be rotated, was produced in year 1. Data from the first two years tasks were included in the first factor analysis and results from all three years tests were included in the second.

Factor Analysis of Tests in years 1 and 2.

Year 1 and 2 test scores (minus spelling, reading and handedness data) were entered into a principal components analysis with the aim of examining the resulting factors, for association with reading, spelling and handedness, in the light of the RS theory. The selection of the sample has already been described in chapter 3.

Method.

Participants. The sample included 391 (199 girls and 192 boys) schoolchildren with a mean age of 134.7 months and a std. dev. of 3.6 months. As explained above 13 children with recognized special needs were excluded before any analysis which involved literacy and one child with a history of severe arm injury was also excluded from analyses of handedness. Three hundred and seventy seven children were left in the main sample.

Procedure. Error scores from 1st and 2nd yr tasks were entered into an SPSS varimax factor analysis. First year tasks were ones of visuo-spatial processing, word discrimination, and phonological processing (nonword spelling and word order, both confusable and non-confusable stimuli). Second year tests were non-verbal intelligence (CPM), phoneme segmentation and visual memory. Measures of handedness and literacy were not included so that they could be used as dependent variables in subsequent regressions. Although not strictly necessary for Varimax rotation (which squares values) all scores which were not errors (visuo-spatial processing and digit span) were converted to errors. The resulting factors were tested, by SPSS correlation and stepwise multiple regression, for an association with reading (2nd year) and spelling (1st year) and handedness. All tasks are listed below together with details if these have not been previously described.

First Year Tasks. First year tasks were presented in class, by Annett and another research assistant, in one double period of approximately 45 minutes.

<u>1.1: Holes Test (laterality).</u> As described earlier (in chapter 3).

<u>1.2: Word Order Memory Task (Confusable and non-confusable, phonology).</u> The adapted auditory short term memory span task (Annett, 1992a) has been previously described in chapter 4 and stimuli may be found in appendix B.

<u>1.3: Word Discrimination Task (literacy).</u> Printed homophone pairs (eg. root - route) were presented (as in Annett, 1992a) with an appropriate sentence to help identify one homophone from each pair (eg. "our route was marked on a map"). Each sentence was spoken aloud by E and the children were asked to indicate the target word with a circle. Any incorrect response was scored as an error. See appendix D for homophone list.

1.4: Spelling Task (literacy).As described in chapter 4 and appendix C.

1.5: Nonword Spelling Task (phonology). As in chapter 4 and appendix E and G.

1.6: Visuo-spatial Task (visual memory). Four shapes (see appendix F) were displayed in turn, by OHP, for 5 seconds each. At the end of each display a 5 second delay was observed before the children were told to pick up their pencils and draw the shapes from memory. Scores were marks awarded for specific features in the drawings (see appendix F for shapes and scoring system). The shapes were part of a new test under development by the National Foundation for Educational Research (NFER) and supplied to Annett for trial in this research.

Second Year Tasks. Second and third year tasks were all presented individually by Annett and Eglinton or Smythe with children being removed from class in pairs.

1.8: Peg board Hand Skill (laterality (Annett, 1970, 1992d) The task was described in chapter 3 and appendix U. Differences between the means for each hand were calculated as a proportion of their sum (pegperc = (((L-R)/(L+R))*100)).

1.9: Hand Preference (laterality). As described in chapter 3 and appendix K.

1.10: Matrices Intelligence (CPM) (cognitive ability). The Coloured Progressive Matrices (Raven, Court & Raven, 1984) was given and scored according to instructions in the manual.

1.11: Word Reading (literacy). Lists C and D of the British Ability Scale (BAS, Elliott, Murray & Pearson, 1978) word reading test were used (see appendix I for wordlists).

1.12: Phoneme Segmentation (adapted from Stuart, 1990 and Bruce, 1964) (phonology). This task was described earlier in chapter 3 and appendix H (word lists and instructions).

1.13: Visual Task (visual recognition). The task was devised by a colleague (Eglinton) from one used by Vellutino (1980). A set of small shapes which could not easily be verbalized was displayed for 20 seconds and then covered. A single item from this display was then shown for 5 secs only, before it too was covered. After a 5 sec. delay the children were asked to select this item from the original display. The number of shapes to be remembered and selected increased one at a time until there were four in the final trial (see appendix J for shapes). Responses which did not indicate all correct shapes, irrespective of order, were scored as errors.

Results.

Factor Analysis of Tests in years 1 and 2.

Two factors, representing verbal and non-verbal processing, were identified from first and second year tests using SPSS principal-components analysis with 1 varimax rotation. Table 5.1 gives the means and std deviations of each variable for the 377 participants in the analysis and table 5.2 gives the factor loadings of all variables.

Table 5.1: Variable means of the 377 participants

Variable	Mean	Std Dev	Range	Min/max
Word order memory (non-confusable)	1.62	1.93	8	0 - 8
Word order memory (confusable)	2.99	2.09	8	0 - 8
Word discrimination	4.72	4.09	30	0 - 30
Nonword spelling	1.49	1.59	6	0 - 6
Visuo-spatial memory	5.82	2.65	12	0 - 12
Phoneme segmentation	0.79	1.39	10	0 - 10
Visual recognition	3.63	1.79	10	0 - 10
CPM	6.41	4.21	25	0 - 25

Table 5.2 Factor Loadings.

	Factor 1	Factor 2
Word discrimination	.77576 *	.20168
Nonword spelling	.75713 *	.08091
Phoneme segmentation	.74242 *	.12167
Word order memory (non-confusable)	.73001 *	.17378
Word order memory (confusable)	.70033 *	.31377
C.P.M.	.28039	.75128 *
Visual recognition	.06855	.71724 *
Visuo-spatial memory	.16772	.71635 *
Eigenvalue	3.49059	1.15761
Total % var.	43.6	14.4

* = loading greater than 0.6

Factor 1 loaded strongly on five tests - word discrimination, nonword spelling, phoneme segmentation and word order memory (non-confusable and confusable). Four of these five tasks were designed to test aspects of phonology. The strongest loading fell on the verbal test of word discrimination, where the sounds of two words were kept constant. Consequently, this factor was named verbal processing.

Factor 2 loaded strongly on the Matrices (CPM), visual recognition for shapes and visuo-spatial memory (drawing shapes from memory). Two of these tasks were intended to measure visual processing but the highest loading fell on the test of non-verbal intelligence (CPM) so this factor was labelled non-verbal processing.

Discussion

All factor analyses were SPSS principal components analyses with Varimax rotation which results in orthogonal factors. Orthogonal factors cannot correlate as they are deliberately separated by 90 degree angles and for this reason can safely be entered together into multiple regressions. However, it could be argued that factors involved in reading and spelling should be expected to correlate making orthogonal factors less suitable than oblique factors. Consequently oblique factors were also examined but were found to be little different from the orthogonal factors above.

Statisticians have disagreed about the criteria on which a decision for accepting factors should be based. A loading of 0.3 indicates that 9% of the variance in a variable is accounted for by that factor. A strict criterion advocates only accepting factors which have loadings of more than 0.6 on at least 4 variables. However, Kline (1994) advises that most reputable factor analysts agree on the (Cattell) scree test as the best solution to the problem of selecting the correct number of factors. During a scree test a plot is made of total variances (eigenvalues) and principal components (or factors). A scree plot then represents the variance of each factor. All factors are accepted until the slope of the plot changes, this becomes the cut off point and any further factors are rejected. SPSS varimax automatically drops any factors with an eigenvalue of less than one. An eigenvalue is a measure of standardised variance with a mean of 0 and standard deviation of 1. As each standardised variable contributes a principal components extraction of 1 a component with an eigenvalue of less than 1 is unimportant and can be ignored (Kinnear and Gray, 1994). Using these criteria for the acceptance of factors, which are used throughout this thesis, the two factors above were accepted.

This analysis clearly resulted in two factors of verbal and non-verbal ability. The first factor (verbal processing) loaded strongly on five tests of nonword spelling, phoneme segmentation, word order memory (non-confusable and confusable) and word discrimination. Four of these five tasks were designed to test phonology. However, the highest loading fell on the test of word discrimination which was not a test of phonology, as sounds in the two words were kept constant. The strong loading of the five tests together indicates that phonological processing alone does not entirely explain verbal ability. Consequently, the term verbal processing was used to represent this factor. Nevertheless it is possible that discriminating between two words which appear to have the same pronunciation (eg. 'son' and 'sun') could involve subtle differences in pronunciation which help guide the listener. If this is true the word discrimination test could also include an aspect of phonological processing. The second factor (non-verbal processing) had it's strongest loading on the matrices task. Whether this represents non-verbal intelligence ('g'), non-verbal reasoning or visuo-spatial ability is debateable but it clearly leads the visuo-spatial tasks in this instance.

Factors and Literacy.

Both factors appeared to represent abilities which are used in the development of literacy so it was expected that they would have a relationship with reading and spelling abilities. The two factors appeared to demonstrate a clear verbal/ non-verbal division. Consequently a difference score was calculated for each individual (verbal factor score - non-verbal factor score) so that positive difference scores indicate better verbal than non-verbal ability and negative scores imply better non-verbal than verbal ability. The distribution of these difference scores was approximately normal (see appendix V) with a mean of 1.6256E-16, std deviation of 1.414 and a range of 9.3 (min. -4.506, max. 4.764).

In order to test the relationship between the factors and literacy, six SPSS regressions were conducted. Three separate regresssions examined the association between, (1) verbal factor scores, (2) non-verbal factor scores, and (3) difference scores between the two factors (verbal-nonverbal) and the first year test of spelling. Three further separate regressions (4 to 6) examined the same relationship for the second year test of reading.

Results.

The means, standard deviations and ranges of the whole sample for variables in this analysis are to be found in table 5.3.

Table 5.3: Means of Factors and Literacy Measures

	Mean	Std Dev.	Range	Min-Max.
Spelling errors	5.042	3.255	10	0 - 10
Reading errors	2.220	2.351	14	0 - 14

N = 377

Spelling: The variability in first year spelling errors which could be accounted for by the verbal factor, the non-verbal factor or the difference between the two factors was examined by three separate regression analyses and details can be found in table 5.4.

Table 5.4: Two Factors and the Difference between them and Variability in Spelling Errors

Variable	R^2	df	F	p	B	SE B	Beta	t	p
Verbal	.432	1, 375	285.3	.0001	2.14	.126	.657	16.89	.0001
Non-verbal	.023	1, 375	8.99	.003	.5	.166	.153	2.998	.003
Verb-Non-v	.127	1, 375	54.65	.0001	.82	.111	.357	7.393	.0001

The verbal factor explained 43% of the variance in the spelling test, the non-verbal factor explained only 2% and the difference between factors explained 12.7% with all three regressions being highly statistically significant (p= 0.0001, p= 0.003, p= 0.0001 respectively). Increasing verbal and non-verbal errors were associated with increasing spelling errors and increasing differences between verbal and non-verbal errors were associated with increasing spelling errors. Consequently poor verbal and non-verbal skills are associated with poor spelling as are poorer verbal skills than non-verbal skills.

Reading: The variability in second year reading errrors which could be accounted for by the verbal factor, the non-verbal factor or the difference between the two factors was examined by three separate regression analyses and details can be found in table 5.5.

Table 5.5: Two Factors and the Difference between them and Variability in Reading Errors

Variable	R^2	df	F	p	B	SE B	Beta	t	p
Verbal	.588	1,375	534.4	.0001	1.80	.0779	.766	23.12	.0001
Non-verbal	.013	1,375	5.022	.026	.27	.1206	.115	2.24	.026
Verb-Non-v.	.212	1,375	101.07	.0001	.766	.076	.4607	10.05	.0001

The verbal factor explained 59% of the variance in the reading test, the non-verbal factor explained only 1% and the difference between factors explained 21%. The regressions of the verbal factor and the difference between the factors were both highly statistically significant (p= 0.0001, p= 0.0001 respectively) and the regression of the non-verbal factor was significant (p= 0.026). Increasing verbal and non-verbal errors were associated with increasing reading errors as were increasing differences between verbal and non-verbal errors. Consequently poor verbal and non-verbal skills were associated with poor reading as are poorer verbal skills than non-verbal skills.

Factors and Handedness.

The RS theory makes predictions about specific deficits so the following analysis aimed to investigate handedness when a dissociation exists between verbal and non-verbal ability. It is predicted by the RS theory that individuals with different types of specific processing difficulties are likely to be found at different ends of the continuum of hand skill. It has been proposed that those with visual deficits are likely to be more dextral than the majority and those with phonological deficits less dextral. It is possible that difficulties with verbal processing, could originate in phonological deficits and difficulties with non-verbal processing could stem from visuo-spatial deficits. If this is true then the above two factors of verbal and non-verbal processing could also be associated in this way with handedness.

Consequently the next question was whether handedness was associated with the two factors. In order to test the relationship between the factors and handedness, nine SPSS regressions were conducted. Three separate regresssions examined the association between (1) verbal factor scores, (2) non-verbal factor scores and (3) difference scores between the two factors (verbal-nonverbal) and the first year test of holeperc. Six more separate regressions examined the same relationship for the second year tasks of peg moving (4 - 6) and hand preference (7 - 9). It was predicted that poor verbal processing would be associated with reduced dextrality and poor non-verbal processing associated with increased dextrality.

Results.

Means, standard deviations and ranges of the whole sample for variables in this analysis can be found in table 5.6.

Table 5.6: Whole Sample Means for Handedness Measures

	Mean	Std Dev	Range	Max-Min.
Holeperc	16.6	15.9	122.1	-45.2 to 76.9
Pegperc	3.8	4.5	29.2	-9.4 to 19.8
Hand preference	2.6	1.9	7	1 - 7

N = 377

The variability in the first year holes measure of laterality which could be accounted for by the verbal factor, the non-verbal factor or the difference between the two factors was examined by three separate regression analyses and details can be found in table 5.7. Details of the same analysis for the second year measures of laterality can be found in table 5.8 (peg board hand skill) and table 5.9 (hand preference).

Table 5.7: Two Factors and the Difference between them and Variability in Hand Skill (Holeperc)

Variable	R^2	df	F	p	B	SE B	Beta	t	p
Verbal	.0161	1,375	6.15	.014	-20.3	8.16	-.127	-2.48	.014
Non-verbal	.00005	1,375	.019	>0.1	1.13	8.23	.007	.137	>0.1
Verb-Non-v	.00899	1,375	3.4	.066	-10.7	5.79	-.095	-1.84	.066

Table 5.8: Two Factors and the Difference between them and Variability in Hand Skill (Pegperc)

Variable	R^2	df	F	p	B	SE B	Beta	t	p
Verbal	.0138	1,375	5.24	.023	-5.3	2.31	-.117	-2.29	.023
Non-verbal	.0003	1,375	.117	>0.1	-.796	2.33	-.018	-.34	>0.1
Verb-Non-v	.00498	1,375	1.88	>0.1	-2.25	1.64	-.071	-1.37	>0.1

Table 5.9: Two Factors and the Difference between them and Variability in Hand Preference

Variable	R^2	df	F	p	B	SE B	Beta	t	p
Verbal	.0106	1,375	4.03	.046	.175	.087	.103	2.01	.046
Non-verbal	.00001	1,375	.004	>0.1	.006	.088	.003	.064	>0.1
Verb-Non-v	.00497	1,375	1.87	>0.1	.085	.062	.071	1.37	>0.1

The verbal factor accounted for approximately 1.6%, 1.4% and 1% of the variance in the holeperc measure of laterality (first year), the pegperc measure (second year) and hand preference (second year) and all three regressions were statistically significant. Increased verbal errors were associated with reduced dextrality in all three regressions. The holeperc and pegperc regressions (with dextral hand skill scores tending to be higher and sinistral scores tending to be lower) were both negative so that verbal errors increased as dextrality decreased. The hand preference regresssion (with group 1 most dextral, group 8 least dextral) was positive so that verbal errors again increased as dextrality decreased. A small proportion of the variance of each of the three measures of handedness was explained by the verbal factor with reduced dextrality being associated with increasing verbal processing errors. However, neither the non-verbal factor nor the difference between the factors were statistically associated with holeperc, pegperc or hand preference.

Discussion (Factors, Literacy and Handedness).

Two factors (verbal and non-verbal processing) were identified from this analysis of first and second year tests and their relationship with literacy was examined. When all data were analysed the verbal processing factor, the non-verbal processing factor and the difference between them explained the variance in literacy in the form of errors on both the second year reading test and the first year spelling task. The verbal factor explained 43% and 59%, the non-verbal factor explained 2% and 1%, and the difference between the two factors explained 13% and 21% of the variance in spelling and reading ability respectively.

Increasing verbal and non-verbal errors were both associated with increasing reading and spelling errors as were increasing differences between verbal and non-verbal errors. This is as would be expected if verbal ability is more strongly associated with literacy as those with large differences in factor scores will be good at verbal processing and those with small differences will be poor.

When a relationship with handedness was examined, the verbal factor, but not the non-verbal or the difference between factors, was associated with handedness on all three measures with poor verbal ability being associated with reduced dextrality. This supported predictions of the RS theory that individuals with a reduced shift to dextrality are at risk for phonological problems.

The RS theory makes predictions for specific difficulties of phonological and visual processing but the factors examined here were less specific (representing verbal and non-verbal processing). The main purpose of this investigation was to attempt to identify the aspect of phonological processing which is predicted by the RS theory to be at risk in those who are to the left of the continuum of handedness. This involves segregating the different components of phonological processing and identifying which one (or more) has a relationship with handedness. The factor analysis described so far has identified only one verbal factor so the following factor analysis included third year data with the expectation that the addition of more specific phonological tasks would isolate more specific phonological factors.

EXPERIMENT 6

Components of phonological processing in children (factors in yrs 1+2+3).

The aim of this analysis was to repeat the above with the addition of the further tests given in year 3. This however involved a reduction in numbers of subjects but the generally recommended criterion of at least 5 subjects for each observed variable was comfortably accommodated and it was well within Kline's (1994) recommended guidelines for factor analyses of a minimum variable to subject ratio of 2:1. Again the resulting factors were tested for their relevance to literacy and their relationship with handedness was examined in the light of the RS theory. Year 1, 2 and 3 test scores (minus spelling, reading and handedness data) were entered into a further principal components analysis with the intention of discovering more specific phonological factors. It was anticipated that at least one phonological factor would be associated with reduced dextrality.

Method

Participants - The sample included 116 schoolchildren (mean age 145.8 mths.). They were tested over all three years (with individual testing in the second and third years). Twenty five percent of the initial sample were seen at third year follow up. These included all children identified as having specific problems of reading who were still present in school, as many as possible with specific problems of spelling and controls from the same classes.

Procedure Error scores from all three years tests of phonological and visual processing were entered into an SPSS factor analysis. Reading, spelling and handedness tasks were not entered as they were to be used as dependent variables in further analysis. Associations with literacy were tested by two separate SPSS stepwise multiple regressions. The dependent variables were reading (schonell reading quotient, third year) in the first regression and spelling (repeat spelling test third year) in the second. Following this the factors' relationship with handedness was examined in the light of the RS theory. Associations with handedness were tested by three SPSS multiple regressions with hand preference, holeperc or pegperc as dependent variables.

Year 1 and 2 Tasks.

As in the previous factor analysis, first year tests were visuo-spatial processing, word discrimination, nonword spelling and word order (both confusable and non-confusable) and second year tasks were CPM, phoneme segmentation and visual shape recognition. Methodologies of these tasks were described in the previous analysis.

Year 3 Tests.

Additional third year tasks in this factor analysis were phonological tests of nonword repetition, phonological memory (digit span forwards and backwards), phoneme discrimination and nonword reading. Two scores (digit span backwards and forwards) were converted to error scores before the analysis.

As for second year tasks children were taken from class in pairs and tested individually, (in parallel) for approximately twenty minutes, by two experimenters (usually Annett and Eglinton or Smythe). In each pair one child wore headphones for the computer tasks while the other was reading and doing other tasks. Methodologies of the reading, spelling and nonword reading tasks were described in chapter 4 and the additional tasks are described below.

1.14: Auditory Memory task (phonology) The (WISC-R) Digit Span was presented as in test instructions in the manual. On the failure of both trials of any item (forwards or backwards) the test was immediately discontinued. One mark was scored for each digit recalled (either backwards or forwards) as in the manual.

1.17: Minimal Pairs Auditory Discrimination Task (phonology) Twelve pairs of nonwords, adapted (by PS) from PALPA 1 (see appendix L), were presented auditorily. The task was to decide if pairs were exactly the same (e.g. "wid, wid") or slightly different (e.g. "bon, mon"). To prevent lip-reading the experimenter held a card in front of her mouth while pronouncing the nonword pairs. Two pairs of practice words ("bus, bus" and "bus, bud"), followed by feedback, began the task and an error was scored for each incorrect decision.

1.18: Nonword Repetition Task (phonology) Two nonword lists (selected from PALPA 8, by PS) were presented auditorily. The lists were balanced for word syllable length and the items were presented in random order (see appendix M for details). The task was to repeat each nonword immediately after it was spoken. The experimenter's mouth was covered, while speaking, to prevent lip reading. One error was scored if a repetition was not entirely accurate.

1.19: Nonword Reading (phonology)

Twelve nonwords from Psycholinguistic Assessments of Language Processing in

Aphasia (PALPA, 36, Kay, Lesser & Coltheart, 1992), for example ked, pretch, glope, were read aloud by the participant. The two lists may be found in appendix N. They were balanced for nonword length and consisted of three each of 3, 4, 5 and 6 letter nonwords. One error was scored for each illegal nonword pronunciation.

Computer administered tasks were also presented on the same occasion but are not used in this thesis.

Results

Table 5.10 shows the means, standard deviations and ranges of the participants on each variable and table 5.11 gives the factor loadings of all variables plus eigenvalues.

Table 5.10: Variable means for the 116 cases in the analysis

Variable	Mean	Std Dev	Range	Min-max.
Word order memory (non-confusable)	2.00	1.97	8	0 - 8
Word order memory (confusable)	3.52	2.09	8	0 - 8
Word discrimination	6.62	4.56	30	0 - 30
Nonword spelling	2.41	1.96	6	0 - 6
Visuo-spatial memory	6.61	2.65	11	0 - 11
Phoneme segmentation	1.38	1.73	10	0 - 10
Visual recognition	3.81	1.91	9	1 - 10
CPM	7.54	4.85	25	0 - 25
Nonword reading	3.26	3.37	12	0 - 12
Digit span forwards	7.57	1.76	8	5 - 13
Digit span backwards	4.32	1.62	8	2 - 10
Minimal pairs	0.25	0.56	3	0 - 3

Data from the nonword repetition task could not be included in the factor analysis as this failed to correlate by at least 0.3 with any other variable (a necessary criterion for inclusion). Data from the minimal pairs task just qualified and was included. An SPSS principal-components analysis identified four factors with 1 varimax rotation. Details of the criteria for the acceptance of factors are to be found in the discussion section of the previous factor analysis.

Table 5.11 Factor Loadings.

Test	Factor 1	Factor 2	Factor 3	Factor 4
Nonword reading	0.83220 *	0.08090	0.11311	0.08547
Nonword spelling	0.80723 *	0.18730		
Word discrimination	0.76589 *	0.25160	0.28294	-0.08229
Phoneme segmentation	0.71298 *	0.30835	0.15518	
Word order (non confusable)	0.23713	0.80936 *	0.13593	
Digit span forwards	0.09649	0.71648 *	-0.05505	0.30051
Word order (confusable)	0.18708	0.69666 *	0.36447	-0.13964
Digit span backwards	0.33022	0.54240 *	0.09754	-0.10093
Visual recognition	0.06576		0.73595 *	
CPM	0.12873	0.23861	0.73550 *	0.28365
Visuo-spatial drawing	0.22538	0.14641	0.67299 *	-0.12335
Minimal pairs		0.06369		0.94726 *
Eigenvalues	4.32551	1.32725	1.18977	1.05809
Total % Var.	36.0	11.0	9.9	8.8

* - loading greater than 0.6

Factor 1 loaded strongly on three tests of phonological processing nonword reading, nonword spelling and phoneme segmentation and one test, word discrimination, which gave the highest loading, in year 2, on the verbal factor. As, in this analysis, the highest loading of this factor was on nonword reading it was tentatively labelled phonological production (or output). This is considered further in the discussion section.

Factor 2 included three tests of auditory processing which involve phonological memory, word confusable, word non-confusable and digit span forwards with a value of greater than 0.65 and a fourth digit span backwards with a value of greater than 0.5. On this basis the factor was named phonological memory.

Factor 3 was similar to factor 2 in the second year factor analysis. Again it loaded strongly on three measures of non-verbal processing, non-verbal intelligence (CPM), visual recognition and visuo-spatial memory for drawing shapes. Consequently as in the previous factor analysis it was labelled non-verbal processing.

Factor 4 depended almost entirely on one test of phonological discrimination (minimal pairs - greater than 0.9) together with two weaker loadings on tests of phonological memory (digit span forwards - 0.30) and CPM (0.28). This factor was labelled phonological discrimination.

Discussion

The first factor loaded strongly on two phonological tasks of nonword reading and nonword spelling followed by the word discrimination task and phoneme segmentation. This supports the view that phonological processing ability is linked to literacy development. However the three phonological tasks (nonword reading, nonword spelling and phoneme segmentation) all involve phonological *production* so possibly this factor could represent this aspect of phonological processing. Indirect support for this suggestion is provided by the tasks of phonological memory (factor 3) and phonological input (factor 4) which did not load strongly on this factor but formed separate factors. Consequently, this first factor appeared to represent an aspect of phonological processing which is neither memory nor perception so it was labelled phonological production (or output).

Factors 2 and 3 clearly represented phonological memory and non-verbal processing, respectively, so they were named accordingly. However factor 4 depended strongly on one test of phonological discrimination (minimal pairs - greater than 0.9) together with two weaker loadings on tests of phonological memory (digit span forwards 0.30) and CPM (0.28). As a result, this factor was labelled phonological discrimination. It is also possible that the factor is one of phonological perception (input) as it could be argued that phonological memory is necessary to retain the sounds of nonwords whilst discriminating between them.

Four Factors and Literacy.

The relationship of the above four factors to reading and spelling was examined by entering them into two SPSS stepwise multiple regressions. In the first the dependent variable was the third year spelling task and in the second it was the third year reading task (RQ, calculated as the conventional formula for reading quotient). This information was available for all participants in year 3.

Results

Table 5.12 shows the means, standard deviations and ranges of the participants for reading and spelling. Details of the stepwise regression of the four factors on third year spelling errors can be found in table 5.13 and of the same analysis for third year reading quotient can be found in table 5.14.

Table 5.12: Whole Sample Means for Reading and Spelling (year 3)

	Mean	Std Dev	Range	Min.-Max.
Spelling errors	7.0	3.23	10	0 - 10
Reading quotient	91.9	15.28	62	60 - 122

Spelling

Table 5.13: Stepwise Multiple Regression of the 4 Factors and Spelling Errors

Step	R^2	df	F	p	Variable	B	SE B	Beta	t	p
1	.5805	1, 114	157.7	.0001	**Ph Prod**	2.59	.206	.762	12.7	.0001
2	.6741	2, 113	116.8	.0001	**Ph Prod**	2.59	.182	.762	14.1	.0001
					Ph Mem	1.04	.182	.306	5.7	.0001
3	.6752	3, 112	77.61	.0001	**Ph Prod**	2.59	.183	.762	14.15	.0001
					Ph Mem	1.04	.183	.306	5.7	.0001
					Non-verb	.115	.183	.034	0.63	>0.1
4	.6756	4, 111	57.8	.0001	**Ph Prod**	2.59	.184	.762	14.096	.0001
					Ph Mem	1.04	.184	.306	5.7	.0001
					Non-verb	.116	.184	.034	0.62	>0.1
					Ph Discr	-0.055	.184	-0.016	-0.3	>0 .1

The four factors jointly explained approximately 68% of the variance of the third year spelling test and the regression was statistically highly significant. A plot of predicted vs observed standardized residuals and a histogram of standardized residuals demonstrated a reasonable fit to a normal distribution. The stepwise regression resulted in a change in R^2 of 0.0936 over phonological production when phonological memory was added to the equation; adding non-verbal processing resulted in a change of only 0.0011 and adding phonological perception changed it by only 0.0004.

The factors of phonological production and phonological memory were both highly significant when explaining the variance in spelling errors but the factors of non-verbal processing and phonological discrimination were not. Increasing phonological production and phonological memory errors were associated with increasing spelling errors.

Reading.

Table 5.14: Stepwise Multiple Regression of the 4 Factors and Reading Quotient

Step	R^2	df	F	p	Variable	B	SE B	Beta	t	p
1	.6191	1, 114	185.3	.0001	**Ph Prod**	-12.2	.899	-0.787	-13.6	.0001
2	.7272	2, 113	150.6	.0001	**Ph Prod**	-12.2	.763	-0.79	-16.0	.0001
					Ph Mem	-5.1	.764	-0.33	-6.7	.0001
3	.7395	3, 112	105.99	.0001	**Ph Prod**	-12.2	.75	-0.79	-16.3	.0001
					Ph Mem	-5.1	.75	-0.33	-6.8	.0001
					Non-verb	-1.72	.75	-0.11	-2.3	.023
4	.7396	4, 111	78.8	.0001	**Ph Prod**	-12.2	.75	-0.79	-16.25	.0001
					Ph Mem	-5.1	.75	-0.33	-6.8	.0001
					Non-verb	-1.73	.75	-0.11	-2.3	.024
					Ph Discr	0.069	.75	0.004	0.095	.925

The four factors jointly explained 74% of the variance in the reading quotient and the regression was statistically significant. A plot of predicted vs observed standardized residuals and a histogram of standardized residuals demonstrated a reasonably good fit to a normal distribution. The stepwise regression resulted in a change in R^2 of 0.1081 over phonological production when phonological memory was added to the equation. Adding non-verbal processing resulted in a change of only 0.0123 and adding phonological perception changed it by only 0.0001.

The factors of phonological production and phonological memory were highly significant and the non-verbal processing factor was significant when explaining the variance in third year reading quotient. As reading quotient is a score of ability (not errors) decreasing phonological production, phonological memory and non-verbal processing errors were all associated with increasing reading ability. Only the phonological discrimination factor failed to explain any variance in reading ability.

Discussion

Four factors of phonological production, phonological memory, non-verbal processing and phonological discrimination or perception were identified. Much of the variance in spelling errors and reading quotient (68% of spelling and 74% of reading at approx 12 yrs) was explained by these four factors.

Both the phonological factors of production and memory explained the variance in third year spelling errors and reading quotient with poor phonological production and phonological memory being associated with poor literacy. However, the factor of phonological discrimination explained the variance in neither reading nor spelling. The non-verbal processing factor explained reading, but not spelling, with poor non-verbal ability being associated with poor reading. Reading involves interpreting visual information but spelling, with no visual cues, could be expected to put greater demands on general memory processes. It could be argued that this difference between reading and spelling could explain the role of the non-verbal processing factor in explaining the variance in reading but not spelling ability but it must be remembered that the non-verbal factor loaded strongly on the task of visual recognition. However the difference found in this sample could also simply be caused by the sample's highly selected nature as participants were chosen because of interesting results on earlier tests.

Four Factors and Handedness.

The relationship of the above four factors to handedness was investigated by entering them into three separate SPSS multiple regressions. Dependent variables were hand skill for hole punching (holeperc) in the first, hand skill for peg moving in the second and hand preference in the third. This information was available for all participants in year three.

Results

Table 5.15 shows the means, standard deviations and ranges of the participants on each measure of handedness. Details of the regression of the four factors on the first year measure of holeperc can be found in table 5.16 and details of the regression on the second year measures of pegperc and hand preference can be found in tables 5.17 and 5.18 respectively.

Table 5.15: Whole Sample Means of Handedness Measures

	Mean	Std Dev	Range	Min.-Max.
Holeperc	15.62	15.59	69.4	-31.6 to 37.8
Pegperc	3.42	4.77	27.0	-8.8 to 18.2
Hand preference	2.48	1.67	7	1 - 7

N = 116

Table 5.16: Multiple Regression of the 4 Factors and Hand Skill (Holeperc)

R^2	df	F	p	Variable	B	SE B	Beta	t	p
0.0162	4, 109	0.449	>0.1	Ph Prod	-9.17	15.66	- 0.056	-0.59	>0.1
				Ph Mem	9.25	15.62	0.056	0.59	>0.1
				Non-verb	-9.24	15.67	-0.056	-0.59	>0.1
				Ph Discr	14.01	15.82	0.084	0.89	>0.1

Table 5.17: Multiple Regression of the 4 Factors and Hand Skill (Pegperc)

R^2	df	F	p	Variable	B	SE B	Beta	t	p
0.02222	4, 111	0.642	>0.1	Ph Prod	-4.14	-0.084	0.134	-0.89	>0.1
				Ph Mem	-5.53	-0.112	0.114	-1.19	>0.1
				Non-verb	-0.012	4.64	-2.39E-04	-0.003	>0.1
				Ph Discr	2.57	4.64	0.052	0.555	>0.1

Table 5.18: Multiple Regression of the 4 Factors and Hand Preference

R^2	df	F	p	Variable	B	SE B	Beta	t	p
0.03110	4, 111	0.891	>0.1	Ph Prod	0.236	.165	0.134	1.43	>0.1
				Ph Mem	0.201	.165	0.114	1.22	>0.1
				Non-verb	0.033	.165	0.019	.20	>0.1
				Ph Discr	-0.008	.165	-0.005	-0.05	>0.1

The four factors explained a small proportion of the variance in handedness, 3.1% of hand preference, 1.6% of holeperc and 2.2% of pegperc but none of the regressions were statistically significant.

Discussion

It was not unexpected that only a small proportion of handedness would be explained in this small and highly selected sample. It seems likely that the considerable reduction in numbers of participants and the very selected groups in the third year weakened the power of this analysis and contributed to the lack of statistical significance. The selection of the third year sample was not representative for handedness or literacy as the children were selected on the basis of their specific problems.

General Discussion

Two factors of verbal and non-verbal processing were identified from first and second year tasks which involved most of the sample. The verbal factor and the difference between the two factors were found to explain (respectively) approximately 43% and 13% of the variance in spelling ability and approximately 59% and 21% of the variance in reading ability which confirmed their importance for these skills. However the non-verbal factor explained only approximately 2% of the variance in spelling ability and 1% in reading ability. When a relationship with handedness was examined, only verbal processing explained a small proportion (1-2%) of the variance in handedness so that poor verbal ability was associated with reduced dextrality.

The RS theory makes predictions for specific difficulties of phonological and visual processing but the factors examined in the second year were not specifically phonological (representing verbal and non-verbal processing). Consequently the second factor analysis included more specific phonological tasks with the expectation that these would result in specific phonological factors. Four factors of phonological production, phonological memory, non-verbal processing and phonological discrimination were identified from this third year analysis.

The four factors, combined, explained a high proportion of the variance in spelling spelling (68%) and reading ability (74%). Phonological production and memory explained some variance in both spelling and reading ability but non-verbal processing explained only reading ability. This could be interpreted as implying that the tests were measuring a large proportion of the non-verbal and phonological processes which are necessary for reading skills but only the phonological processes which are necessary for spelling skills. Alternatively it could be that phonological production and memory are important, at this age, for both reading and spelling but non-verbal processing is only important for reading. Some support for this comes from Frith's argument that spelling and reading do not develop in tandem and different skills are involved at different stages. It must be remembered though that the non-verbal factor loaded strongly on the task of visual recognition. However, overall, the separation of different phonological factors, of which some explained reading and spelling, supported the hypothesis that phonological processing consists of separate component processes of which some, or all, are necessary for the development of literacy.

The four third year factors did not significantly explain the variance in handedness but the considerable reduction in numbers in the third year analysis is likely to have weakened the power of the analysis. The third year sample was also not representative for handedness or literacy as the children were especially selected on the basis of their specific problems.

An important aim of this thesis was to separate phonological processing into its component processes. As yet this had only partially been achieved with the identification of phonological factors of production, memory and discrimination. However these third year factors could not be treated with complete confidence for several reasons. Firstly the factors were derived from a sample which included a reduced number of participants and was highly selected, being chosen for their interesting results on earlier tests.

Other limitations on some of the third year factors were difficulties associated with two of the specific phonological tasks used in the third year. Data from the nonword repetition task could not be included in the factor analysis as it failed to correlate, by at least 0.3, with any other variable (widely accepted as the criterion for inclusion in factor analyses). This limited the analysis and could have resulted in the failure to identify a clear factor of phonological production. A further problem with the nonword repetition task was that it involved only a small number of relatively short and simple nonwords which were not likely to have been sufficiently complex to discriminate between children with or without a problem (see Rack, Snowling and Olsen, 1992, for a review indicating the necessity of complex nonwords).

In addition three problems affected the minimal pairs task of auditory discrimination. Firstly the data only just qualified for the correlation criterion of entry into factor analysis (correlation of at least 0.3). Secondly the task was poor at differentiating deficits in phonological discrimination as there were only a few items in the list of stimuli. Finally the nonwords were probably not sufficiently complex to identify deficits in processing (see Rack, Snowling and Olsen review as above).

These considerations led to the planning of another experiment, with undergraduate participants and more complex tasks. This was designed with the intention of better discriminating the different aspects of phonological processing.

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Chapter 6

Components of Phonological Processing in Unselected Undergraduates.

Annett (1999) described data, for undergraduate's lexical skills and handedness, which were collected over several cohorts. I took the opportunity, in some of these studies, to include in the test battery two contrasting tests of phonology (rhyme decision and Benton phoneme discrimination) in order to investigate, in undergraduates, two different types of phonological processing.

EXPERIMENT 7

Group tests of phonological processing in unselected undergraduates.

Introduction.

Annett (1985) has predicted an association between poor phonology and reduced dextrality. The question remains of whether this is true for all aspects of phonological processing. However, many aspects of phonological processing cannot be tested on large numbers of subjects as individual presentation is necessary for suitable tasks (eg. nonword reading, phoneme segmentation etc. which require individual verbal responses). In order to test a maximum number of participants for specific phonological difficulties, this experiment used written group tasks of phonological awareness (nonword rhyme decision) and phonological discrimination (Benton Phoneme Discrimination, 1983). Individuals making many errors on tasks of rhyme decision and/or phonological discrimination were expected to be less dextral, in handedness, than the majority (with average and few errors). Consequently handedness was examined in the first analysis. The second analysis, however, was concerned with the genetic aspects of the RS theory so the handedness of relatives of the two groups was examined. Predictions of a genetic influence on phonological processing led to the hypothesis that the relatives of those with phonological deficits would include more left handers than relatives of those without deficits.

Method.

Participants - The sample included 321 first year psychology undergraduate volunteers (259 females and 62 males) with an age range of 18-48 yrs (mean age 20.5 yrs., S.D. 5.5 yrs.). Three year cohorts of undergraduates were used to complete the sample *(1st yr* - 139 undergraduates, 115 females, 24 males; *2nd yr* 89 undergraduates, 68 females, 21 males; *3rd yr* 93 undergraduates, 66 females, 17 males). Before analysis data from 23 students whose first language was not English were excluded.

Design - The main purpose of this analysis was to investigate, in undergraduates, two different types of phonological processing (phonological discrimination and rhyme decision). The analysis proceeded through stages as follows:

a) Are either of these types of phonology associated with handedness?
b) Are findings for phonology associated with handedness and the handedness of relatives?

Procedure. - Tests of nonword rhyme decision, Benton phoneme discrimination, hand preference and peg moving were used for a cross-sectional survey of three one year samples of first year undergraduates. Familial handedness was ascertained from family trees completed by the undergraduates. Tasks were presented to project volunteers in groups as part of supervised third year student project research. Other tests of cognitive ability were administered, by the experimenter, on the same occasion but these are not relevant here and will be described elsewhere.

2.1: Hand skill for peg moving (laterality). This was measured by the participants working in pairs so that each timed their partners hand skill, on an Annett pegboard, under the instruction of experimenters. Further details of the task can be found in the Wellcome project section (chapter 3) and appendix U.

2.2: Hand preference (laterality). Participants worked in pairs to observe hand preference for the 12 items of the A.H.P.Q. under the instruction of experimenters. Further information can be found in the Wellcome project section (chapter 3) and appendix K.

2.3: Family handedness questionnaires. (laterality). Family trees of relatives handedness (L or R) were completed by the undergraduates during the same session. These were described in chapter 3 and an example may be found in appendix O.

2.4: Benton Phoneme Discrimination Test (phonology). The Benton Phoneme Discrimination Test (Benton, Hamsher, Varney & Spreen, 1983) was presented in a quiet room by tape recorder. Published test instructions were intended for neurological assessment of aphasics so they were adapted slightly for normal subjects, as follows.

"You will hear pairs of nonwords and I would like you to make a tick if both parts of the pair are exactly the same and make a cross if the two parts differ in any way. The difference could be a vowel or a consonant. I will give you two examples - If I say 'loof-loof' they are the same so you would make a tick. If I say 'loof-noof' they are different so you would make a cross."

The test consists of 30 tape recorded pairs of nonsense words spoken by an adult male (see appendix Q for Benton nonword list). In 15 test items the word pairs differ in one phonemic feature, with the difference primarily involving vowels and liquid consonants. Each word,with one exception, that appears in a "same" pair also appears in a "different" pair. In each block of 10 trials, five items are the same and five are different. One mark was scored for each error whether the stimuli was "same" or "different".

2.5: Nonword rhyme decision (phonology). A printed list of 20 pairs of pronouncable nonsense words, (10 rhyming and 10 non-rhyming pairs from Besner, Davies & Daniels, 1981, see appendix P), were presented as group tests in the same situation.

Subjects were instructed not to make any sound while they were working and that rhyming pairs were to be ticked and non-rhyming pairs were to receive a cross. The task was explained and illustrated with the aid of two examples ("swoin'/ "toyne" and "quoz"/"fint"). Subjects were asked to work as quickly as possible and told that they had 55 seconds to complete the task which was stopped promptly at the end of this time. Errors and blanks were recorded by the experimenters.

<u>Results</u>

Nonword rhyme errors and Benton Phoneme Discrimination errors were not normally distributed because most subjects made few errors. Approximately 70% (210) made 1 or fewer nonword rhyme errors and there was a maximum of 14 errors out of a possible 20. Approximately 64% (192) made 3 or fewer Benton phoneme discrimination errors with a maximum of 12 errors out of a possible 30. Table 6.1 gives the means and standard deviations of the whole sample for nonword rhyme errors and Benton phoneme discrimination errors.

Table 6.1:

Whole Sample Means for Nonword Rhyme and Benton Phoneme Discrimination

Variable	Mean	SD
Nonword rhyme errors	1.30	1.93
Benton Phoneme Discrimination errors	3.07	1.57

Handedness and Two Types of Phonology

For the present purposes standardized error scores were derived, by SPSS, for nonword rhyme and Benton Phoneme Discrimination. Mean standardized error scores were then compared, by two SPSS oneway ANOVAs, for groups classified for hand skill and hand preference sub-group. Contrasts, where appropriate, are by Least Significant Difference. Hand skill groups were defined by their bias to dextrality i.e. R-L% pegs 0-2.0 *(no bias)*, 2.1-5.0 (*mild bias*), 5.1-8.0 *(moderate bias)* and 8.1-10.0 *(strong bias)* (similar to those in Annett and Manning, 1989) with a whole group mean of 4.77 (s.d. 0.81, range 0 - 10).

Table 6.2 gives the findings, for mean standardized nonword rhyme and phoneme discrimination error scores plus standard deviations, of the four hand skill groups. The means are also illustrated in figure 6.1 as this makes the pattern of results clear.

Table 6.2: Four Hand Skill groups and Standardized error scores

			Nonword Rhyme		Phoneme Discrimination	
R-L% P	Bias to Dextrality	N.	Mean z score	S.D.	Mean z score	S.D.
0-2.0	Absent	60	0.181	1.158	-0.214	0.971
2.1-5.0	Mild	89	-0.029	1.068	-0.031	1.027
5.1-8.0	Moderate	87	-0.091	0.814	0.189	1.008
8.1-10.0	Strong	61	-0.004	0.982	-0.014	0.96

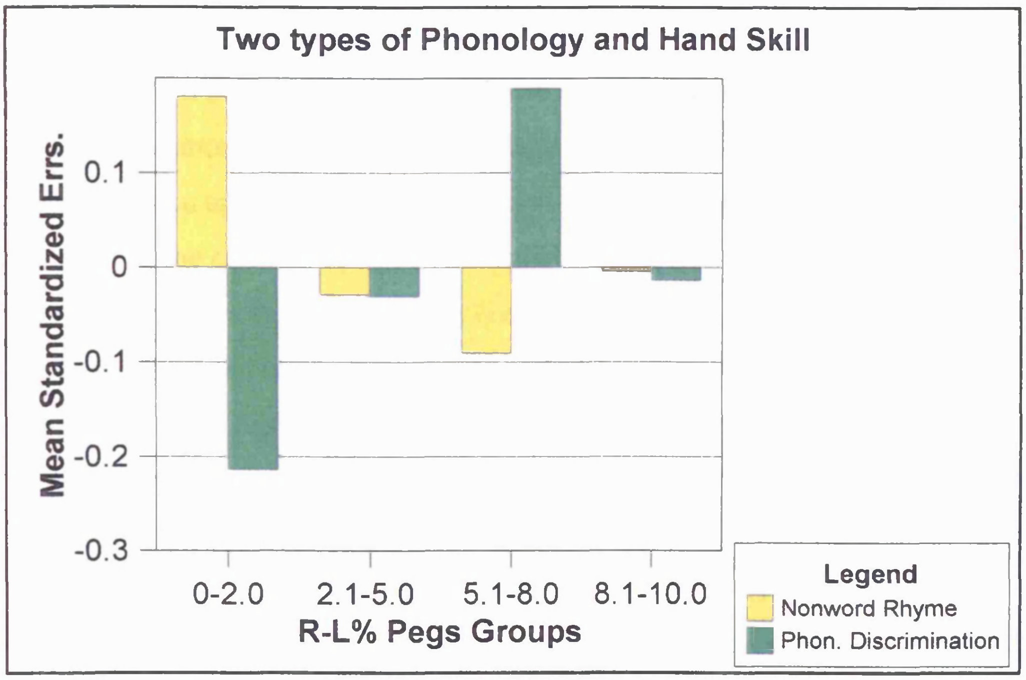

Figure 6.1: Mean standardized error scores (Benton phoneme discrimination and nonword rhyme) for 4 groups with different degrees of bias to dextrality in peg moving (0-2.0 no bias, 2.1-5.0 mild, 5.1-.8.0 moderate and 8.1-10.0 strong bias).

When considering nonword rhyme the least dextral group (i.e. 0-2.0 R-L% pegs and no bias to dextrality) made more errors than the three more dextral groups. This was as expected from predictions of the RS Theory but differences between the groups were not significant ($F(3, 293) = 0.9234$, $p > 0.1$).

However, there appeared to be a different pattern for phoneme discrimination means (in the opposite direction to predictions) but this was also not statistically significant ($F(3, 293) = 1.9979$, $p = 0.114$.). The no bias group made fewer phoneme discrimination errors while the moderate bias group made most and a highly significant contrast ($t = -2.98$, $df = 145$, $p = 0.003$) was found between these two groups. It can be seen from figure 6.1 that the remaining two groups were both intermediate and similar for both types of phonological errors.

Discussion

Overall differences between the groups were not statistically significant but surprisingly, and against expectations, those participants with Benton phoneme discrimination problems appeared to be to the right of the continuum of handedness. Figure 6.1 demonstrates how those *without* difficulties in Benton phoneme discrimination appeared to have no bias to dextrality and difficulties increased until the position on the continuum where it would be expected to find a maximum of individuals with a shift to dextrality (i.e. the moderate bias group). A highly significant contrast was found between these two groups with either no bias to dextrality or a moderate bias to dextrality. These two positions on the handedness continuum are of particular interest because they are expected, from predictions of the RS Theory, to include most individuals of the two homozygote genotypes. The highest frequencies of those with the rs-- genotype are expected to be found where there is no bias to dextrality and the highest frequencies of those with rs++ genotype are expected to be found where there is a consistent bias to dextrality.

Figure 6.1 also illustrates how nonword rhyme difficulties were at a maximum in the position on the hand skill continuum which would be expected for a group with no bias to dextrality, although no statistically significant differences were found. These difficulties declined as dextrality increased to the position on the continuum where it would be expected to find the maximum number of participants with a shift to dextrality (i.e. the moderate bias group).

All trends for nonword rhyme decision were in the predicted direction while those for phoneme discrimination were in the opposite direction. The RS theory predicts that individuals with phonological deficits are likely to be found to the left of the handedness continuum although until now no specific phonological deficits have been implicated. However, the RS Theory also predicts the existence of different deficits at each end of the continuum of handedness so it was necessary to investigate further the surprizing result of this analysis.

Handedness and a Dissociation between Phoneme Discrimination and Nonword Rhyme

In order to investigate the above results further mean standardized scores for the two different types of phonological processing (nonword rhyme discrimination and Benton phoneme discrimination) were compared, by SPSS MANOVA, over the four groups of varying hand skill above (no bias, mild, moderate and strong bias).

Results

Hand skill means and standard deviations etc. for the whole group have already been presented in the previous section (see page 144). Table 6.1 and figure 6.1 give the mean errors (plus standard deviations and Ns.) for non-word rhyme errors and Benton phoneme discrimination errors of the four hand skill groups.

The least dextral group (no bias) made most nonword rhyme errors and least phoneme discrimination errors (poorer rhyme ability than discrimination) while in contrast the group with a moderate bias to dextrality made least nonword rhyme discrimination errors and most phoneme discrimination errors (better rhyme ability than discrimination. The remaining two groups (mild and strong bias) made similar numbers of errors on both types of phonological processing with standardized means which were close to 0 indicating similar ability in nonword rhyme and phoneme discrimination.

Main effects for type of phonological processing ($F(1, 293) = 0.16$, $p > 0.1$) and handedness ($F(3, 293) = 0.19$, $p > 0.1$) were not statistically significant but there was a significant interaction between the two different types of phonological processing and bias to dextrality ($F (3, 293) = 2.91$, $p = 0.035$).

Discussion

The statistically significant interaction found in this analysis between the two different types of phonological processing (nonword rhyme decision and Benton phoneme discrimination) and hand skill was a surprising new result. The Annett RS Theory predicts a risk for phonological processing deficits in those who are to the left of the handedness continuum and figure 6.1 shows the expected pattern for nonword rhyme with difficulties at a maximum in the position on the hand skill continuum which would be anticipated for a group with no bias to dextrality. These difficulties declined as dextrality increased to the position on the continuum where it would be expected to find the maximum number of participants with a shift to dextrality (i.e. the moderate bias group). However figure 6.1 also demonstrates that those *without* difficulties in Benton phoneme discrimination were not biased to dextrality and difficulties increased until the position on the continuum where a maximum of individuals with a shift to dextrality (i.e. the moderate bias group) would be expected. The previous analysis found a highly significant contrast between these two groups with either no bias to dextrality or a moderate bias to dextrality.

These two positions on the handedness continuum are of particular interest because they are expected, from predictions of the RS Theory, to include most individuals of the two homozygote genotypes. The highest frequencies of those with the rs-- genotype are expected to be found where there is no bias to dextrality and the highest frequencies of those with rs++ genotype are expected to be found where there is a consistent bias to dextrality.

Nonword Rhyme Decision Minus Benton Phoneme Discrimination

In order to investigate the above results further a difference score was calculated, for each individual, between the two standardized scores of different phonological processing abilities (nonword rhyme decision minus Benton phoneme discrimination).

A positive difference score indicates a better ability in phonological discrimination than in nonword rhyme while a negative difference score indicates better ability in nonword rhyme than in phonological dicrimination. the difference scores formed a good approximation to a normal distribution (see appendix X) with a mean of 1.8534E-16, sd 1.414, range -4.427 to 5.554). Mean difference scores were compared by SPSS ANOVA for the 7 Annett hand preference sub-groups.

Results

When considering the whole group there was a mean Annett hand preference sub-group of 2.13 (s.d. 1.79, range 7, min. 1, max 8, minus group 5 as explained in chapters 1 and 3). Figure 6.2 shows the mean standardized difference scores (nonword rhyme decision minus Benton phoneme discrimination) for each hand preference sub-group and table 6.4 gives the corresponding standard deviations.

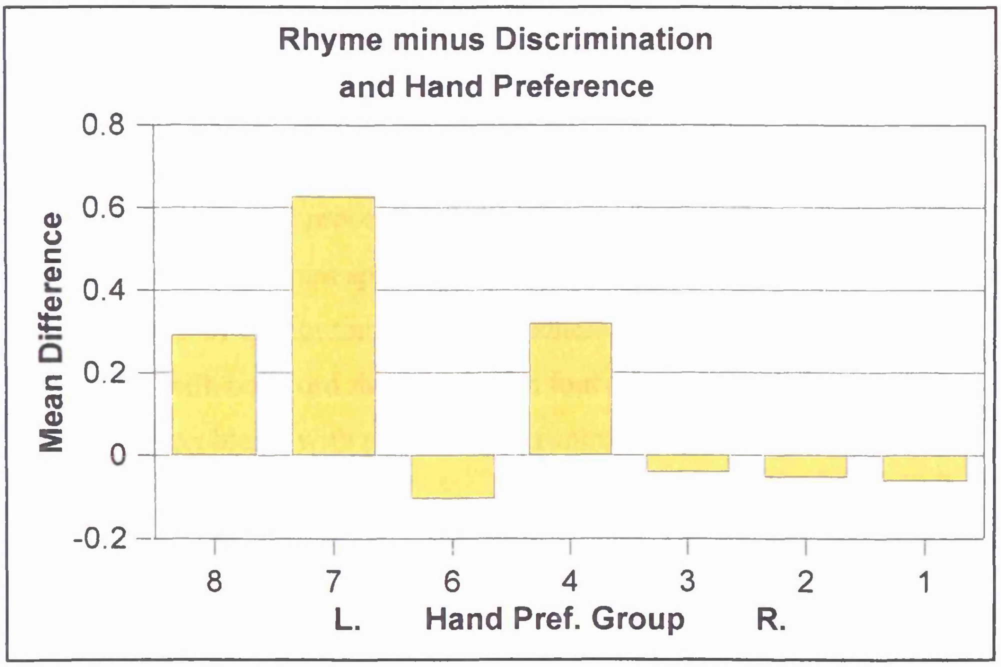

Figure 6.2: Mean difference scores (standardized nonword rhyme errors minus standardized Benton phoneme discrimination errors) for the 7 Annett hand preference sub-groups (8, least dextral to 1, most dextral).

Table 6.4: Hand Preference sub-groups and Mean Standardized Difference Scores.

Hpref.	N.	Mean Std. Diff. score	S.D.
1	181	-0.0611	1.405
2	30	-0.0526	1.036
3	28	-0.0401	1.077
4	31	0.3199	1.500
6	16	-0.1047	1.602
7	6	0.6276	1.892
8	6	0.2923	1.421

One group of left handers (sub-group 7) had the highest difference score (mean diff. = 0.6276, poorer rhyme than discrimination) while the three most dextral groups, sub-groups 1, 2 and 3 (mean diff. -0.0611, -0.0526, -0.0401 respectively) and the most dextral of left handed groups, sub-group 6 (mean diff. = -0.1047) had the lowest (better rhyme than discrimination). There were no statistically significant differences between the 7 hand preference sub-groups for mean difference scores ($F(6, 291) = 0.716$, $p > 0.1$) but there was a non-significant linear trend ($F(1, 6, 291) = 0.618$, $p = 0.072$).

Discussion

A statistically significant interaction demonstrated a clear dissociation between the two forms of phonological processing over differing levels of bias to dextrality in hand skill. Deficits in different specific phonological processing abilities were found at different parts of the continuum of handedness. Figure 6.1 illustrates the specific difficulties with nonword rhyme decision found in those with no bias to dextrality and the specific problems with phoneme discrimination in those with the typical bias to dextrality.

Figure 6.2 shows how hand preference sub-groups 4, 7 and 8 which are expected to include fewer individuals with the typical shift to dextrality appear to have specific difficulties with nonword rhyme decisions and sub-groups 1, 2, 3 and 6 which are expected to include most individuals with a shift to dextrality have smaller specific difficulties with phoneme discrimination. These differences were not statistically significant, but there was a non-significant trend. Group 6, as the left handed group with most right tendencies was argued by Annett (1992c) to include many individuals with the typical shift to dextrality. If this is true the group would include many with no problem with nonword rhyme decision and consequently a low difference score as was found in this analysis. In contrast sub-group 4 is the right handed group which was argued to include most individuals who lack the typical shift to dextrality, but use the right hand because of social pressures. As predicted specific deficits in nonword rhyme ability were found in those with no bias to dextrality (sub-groups 4, 7 and 8) but unexpectedly specific deficits in phonological discrimination appeared to be associated with the typical shift to dextrality (sub-groups 1, 2, 3 and 6).

This pattern of results for differences in right and left hand preference groups is similar to those found by Annett (1992c) for spatial ability in 14-15 year old males. Annett's (1992c) study found better scores on a task of spatial ability in sub-groups 7 and 8 for left handers, and in sub-groups 3 and 4 amongst right handers. Poor scores were also found in sub-group 6 for left handers and in sub-groups 1 and 2 (right handers). In both of these studies (Annett, 1992c and the present one) the more sinistral sub-groups, amongst right and left handers, performed better than sub-groups with strong dextral tendencies. Similar features to this pattern of findings had been noted in earlier samples and these were described by Annett (1992c). They included Raven's matrices scores in primary school children (Annett and Manning, 1989, where the highest means were found in sub-groups 8 and 4 while the lowest was in sub-group 6) and an unpublished study of visual orientation of "little men" figures in backward or frontward facing positions in polytechnic students (Ratcliff, 1979) where good scores were found in classes 8 and 4 while class 6 was particularly poor.

Family Handedness and a Dissociation between Nonword Rhyme and Phoneme Discrimination

The RS theory is a genetic theory which makes predictions involving a genetic influence upon phonological processing. If the difference in handedness, found in the previous analysis for the two different types of phonological deficit, is influenced by a genetic factor then the handedness of relatives of individuals in the different groups should also vary. In order to investigate this further the handedness of relatives of individuals in groups with varying difference scores were also compared. For this purpose the standardized difference scores were divided into 3 groups:

a) a difference score of < -1 s.d. (a difficulty with phoneme discrimination but good nonword rhyme ability),
b) a difference score between -1 and +1 s.d. (no problem with either test)
c) a difference score of > +1 s. d. (a difficulty with nonword rhyme but good phoneme discrimination ability).

The three groups were compared, by SPSS chi-square, for personal handedness before being compared for paternal, maternal and sibling handedness. It was predicted that if it is the case that the group with a difficulty with phoneme discrimination, but not nonword rhyme, includes many with rs++ genotype then that group would include few left handers and there would be few left handed relatives. It was also predicted that if it is the case that the other group included many with rs-- genotype then that group with a problem with nonword rhyme, but not phoneme discrimination, was expected to include many left handers and to have many left handed relatives.

Results.

Overall the whole sample consisted of 22% with poor Benton phoneme discrimination but not poor nonword rhyme discrimination, 54.5% with neither problem and 23.5% with poor nonword rhyme discrimination but not poor Benton phoneme discrimination. In total 269 (approximately 96%) were right handed and 28 (approximately 9.4%) were left handed writers.

The percentage and numbers of each hand preference sub-group in the three standardised difference groups can be found in table 6.5 and the percentages are illustrated in figure 6.3. .

Table 6.5: Hand Preference sub-groups and standardized difference scores.

	Annett Hand Preference Sub-Groups						
Difference groups	**1**	**2**	**3**	**4**	**6**	**7**	**8**
< -1 sd poor Benton, good rhyme	25%	20%	14%	16%	31%	0%	0%
n (total 65)	45	6	4	5	5	0	0
-1 to +1 sd no problem	55%	70%	75%	48%	38%	67%	84%
n (total 162)	90	21	21	15	6	4	5
> +1 sd poor rhyme, good Benton	20%	10%	11%	36%	31%	33%	16%
n (total 70)	45	3	3	11	5	2	1
Total N (100%)	181	30	28	31	16	6	6

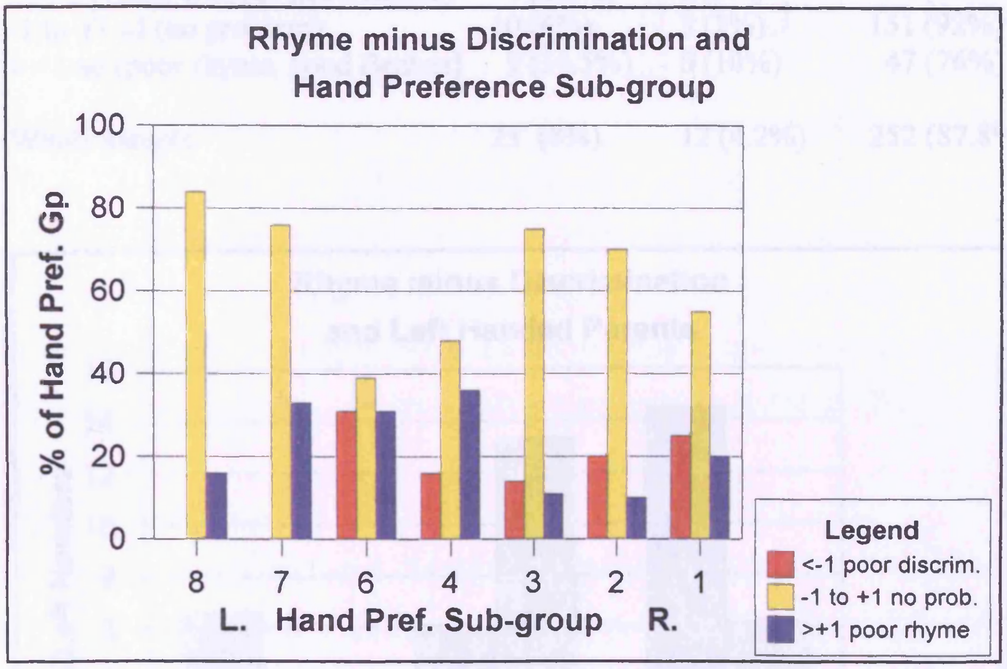

Figure 6.3: The percentage of each Annett hand preference sub-group falling into each of the three rhyme minus discrimination groups (poor discrimination/ good rhyme, no problem and poor rhyme/ good discrimination).

Overall poor rhyme and good discrimination was more prevalent at the left while the reverse was more prevalent at the right but no statistical significance was found (chi-sq. (12) = 14.736, p >0.1) and assumptions of the test for expected frequencies of less than 5 were violated by 38% of the cells.

Parental Handedness

The classification for parental handedness was left, mixed or right and overall the sample consisted of 87.8% right, 4.2% mixed and 8% left handed fathers and 89.2% right, 1.7% mixed and 9.1% left handed mothers. Table 6.6 lists the numbers and percentages of left, mixed and right handed fathers of individuals in each standardized difference group and table 6.7 lists the same information for mothers. Figure 6.4 illustrates the percentage of left handed parents of individuals in the three groups.

Table 6.6: Paternal Handedness in difference score groups

Difference groups	Left (%)	Mixed (%)	Right (%)	Total
< -1 sd (poor Benton, good rhyme)	4 (6.6%)	3 (5%)	54 (88.4%)	61
-1 to +1 sd (no problem)	10 (6%)	3 (2%)	151 (92%)	164
> +1 sd (poor rhyme, good Benton)	9 (14.5%)	6 (10%)	47 (76%)	62
Whole sample	23 (8%)	12 (4.2%)	252 (87.8%)	287

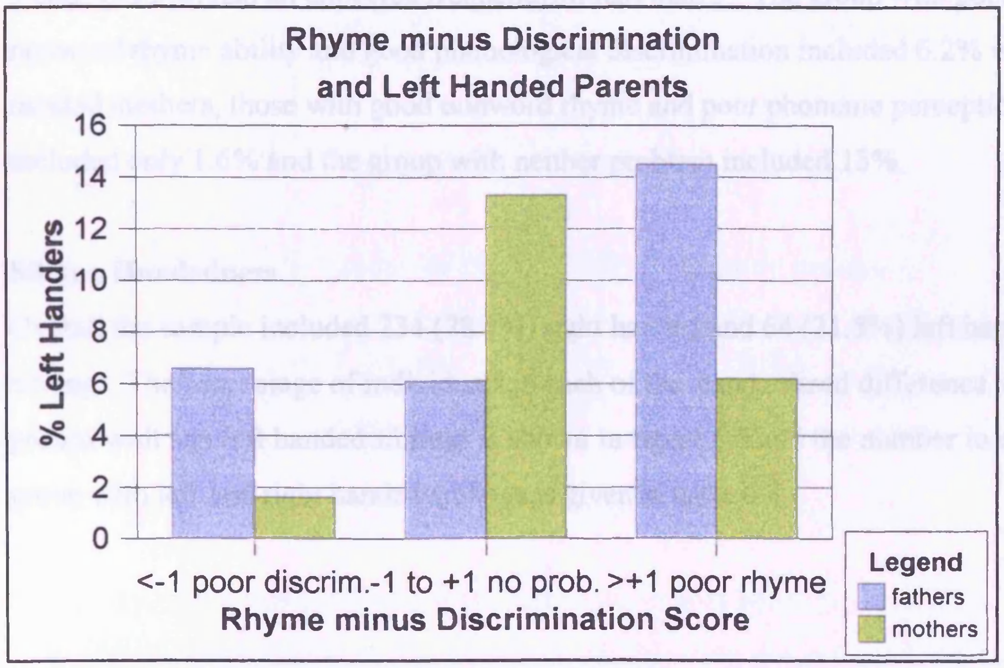

Figure 6.4: The percentage of left handed parents of individuals in each of the three rhyme minus discrimination groups (poor Benton discrimination not rhyme, no problem and poor rhyme not Benton).

The three groups varied for paternal handedness (statistically significant chi. sq. (df 4)=

12.2726, p = 0.015) but the test violated the assumption for expected frequencies < 5 as 4 cells (40.0%) had an expected frequency of less than 5. The group with poor nonword rhyme ability and good phonological discrimination included 14.5% left handed fathers while those with good nonword rhyme and poor phoneme discrimination and those with neither problem included approximately 6% of left handed fathers.

Table 6.7: Maternal Handedness in difference score groups

Difference groups	Left (%)	Mixed (%)	Right (%)	Total
< -1 sd (poor Benton, good rhyme)	1 (1.6%)	0 (0%)	63 (98.4%)	64
-1 to +1 sd (no problem)	22 (13.3%)	2 (1.2%)	142 (85.5%)	166
> +1 sd (poor rhyme, good Benton)	4 (6.2%)	3 (4.6%)	58 (89.2%)	65
Whole sample	27 (9.1%)	5 (1.7%)	263 (89.2%)	295

Maternal handedness also varied between the three groups (significant chi. sq. (df 4)= 13.169, p = 0.01048) but again violated the assumption of expected frequencies < 5 as 3 cells (33.3%) had an expected frequency of less than 5. The group with poor nonword rhyme ability and good phonological discrimination included 6.2% with left handed mothers, those with good nonword rhyme and poor phoneme perception included only 1.6% and the group with neither problem included 13%.

Sibling Handedness

Overall the sample included 234 (78.5%) right handed and 64 (21.5%) left handed siblings. The percentage of individuals in each of the standardized difference score groups with any left handed siblings is shown in figure 6.5 and the number in each group with left and right handed siblings is given in table 6.8.

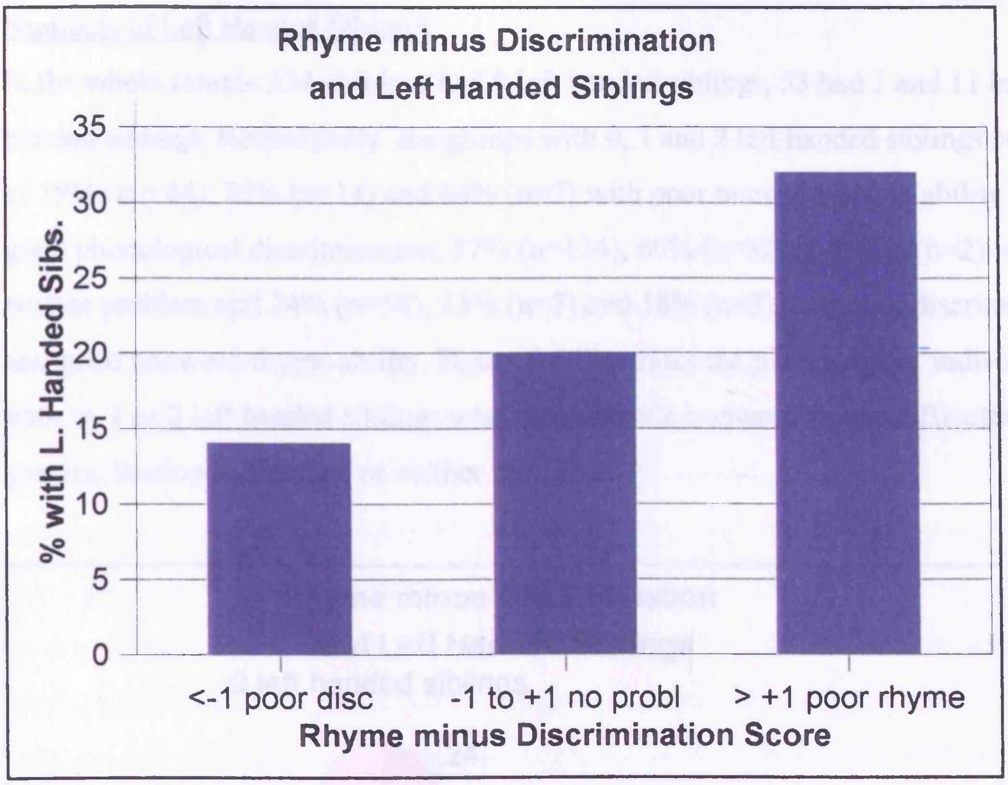

Figure 6.5: The percentage of individuals in each of the three rhyme minus discrimination groups (poor Benton discrimination but good rhyme, no problem and poor rhyme but good Benton) who have left handed siblings.

Table 6.8: Left handed Siblings in difference score groups

Difference groups	Left (%)	Right (%)	Total
< -1 sd (poor Benton, good rhyme)	9 (14%)	56 (86%)	65
-1 to +1 sd (no problem)	34 (20%)	134 (80%)	168
> +1 sd (poor rhyme, good Benton)	21 (32%)	44 (68%)	65
Whole sample	64 (21.5%)	234 (78.5%)	298

Those with poor nonword rhyme ability and good phonological discrimination included 32% with left handed siblings, those with no problem with either included 20% and those with poor discrimination and good nonword rhyme included 14% with left handed siblings (chi-sq. (2)= 6.919, p = 0.031, statistically significant and no cells violated assumptions of less than 5).

Numbers of Left Handed Siblings

In the whole sample 234 children had 0 left handed siblings, 53 had 1 and 11 had 2 left handed siblings. Respectively the groups with 0, 1 and 2 left handed siblings consisted of 19% (n = 44), 26% (n=14) and 64% (n=7) with poor nonword rhyme ability and good phonological discrimination, 57% (n=134), 60% (n=32) and 18% (n=2) with neither problem and 24% (n=56), 13% (n=7) and 18% (n=2) with poor discrimination and good nonword rhyme ability. Figure 6.6 illustrates the percentage of individuals with 0, 1 or 2 left handed siblings who have specific nonword rhyme difficulties, specific Benton difficulties or neither problem.

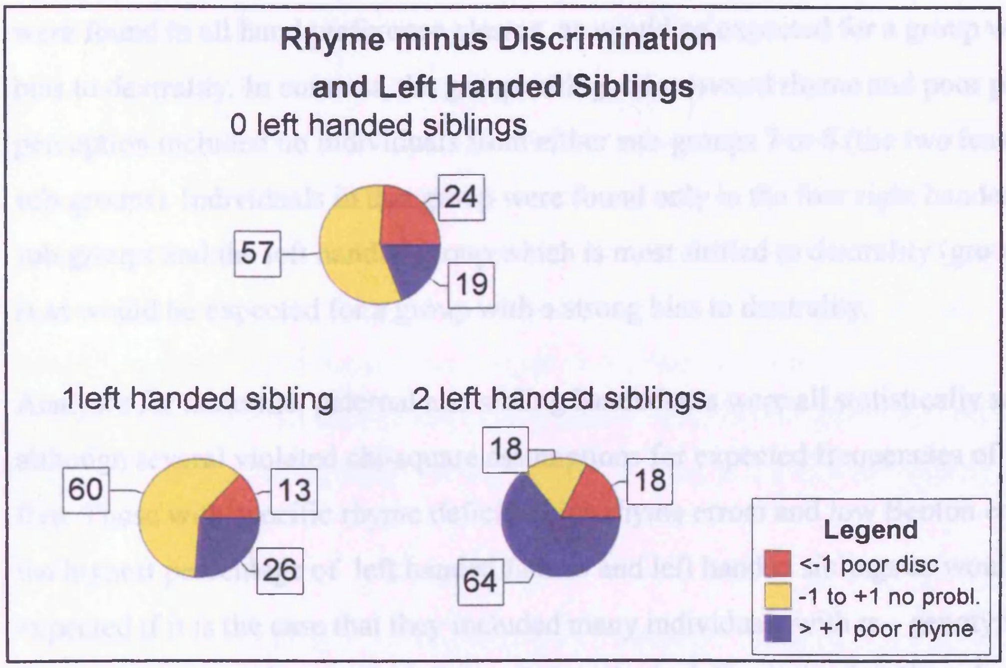

Figure 6.6: Percentages of groups with 0, 1 or 2 left handed siblings with varying mean rhyme minus discrimination difference scores (poor discrimination/ good rhyme, no problem and poor rhyme/ good discrimination).

Chi-square was highly statistically significant (chi. square (4)=15.685, $p = 0.003$) but assumptions for expected frequencies of less than 5 were again violated for 2 out of 9 cells. The three groups did not however vary for numbers of right handed siblings (chi square (df 12)= 9.033, $p > 0.1$) or total siblings (chi square (df 12)= 13.338, $p > 0.1$) but again assumptions for expected frequencies of less than 5 were again violated.

Discussion

The three dissociation groups were found to vary considerably in maternal, paternal and sibling handedness. They also appeared to vary in personal handedness (those with poor rhyme and good discrimination included 32% of left handers while those with poor discrimination and good rhyme included only 14%). Although statistical significance was not found poor rhyme and good discrimination was more prevalent at the left while the reverse (poor discrimination and good rhyme) was more prevalent at the right. The group with poor nonword rhyme ability and good phonological perception included 31%, 33% and 16% of the left handed sub-groups 6, 7 and 8 respectively (the three least dextral sub-groups). Individuals in this phonological group were found in all hand preference classes, as would be expected for a group with no bias to dextrality. In contrast, the group with good nonword rhyme and poor phoneme perception included no individuals from either sub-groups 7 or 8 (the two least dextral sub-groups). Individuals in this group were found only in the four right handed sub-groups and the left handed group which is most shifted to dextrality (group 6). This is as would be expected for a group with a strong bias to dextrality.

Analyses for maternal, paternal and sibling handedness were all statistically significant although several violated chi-square assumptions for expected frequencies of less than five. Those with specific rhyme deficits (high rhyme errors and low Benton errors) had the highest percentage of left handed fathers and left handed siblings as would be expected if it is the case that they included many individuals with rs-- genotype. However, those with specific deficits of phonological discrimination (low rhyme errors and high Benton errors) demonstrated a different pattern as they had the lowest percentage with left handed mothers, fathers and siblings as would be expected if it is the case that they included many individuals of rs++ genotype. The central group with no specific deficit (with rhyme or discrimination) were found in all hand preference classes as would be expected for a group with a normal degree of dextral bias and they included a small percentage of individuals with left handed fathers and an intermediate percentage with left handed siblings as would be expected if this group included many individuals of the rs+- genotype. The puzzling question of the high number of left handed mothers in the group with neither phonological problem is discussed in the final chapter.

When numbers of left handed siblings were examined those with two left handed siblings included a majority (64%, n= 7) with specific rhyme deficits (high rhyme errors and low Benton errors). It can be seen in figure 6.6 that in contrast the majority of those with one (60%, n= 32) or no (57%, n= 134) left handed siblings had no problems with either test. In addition those with specific deficits of phonological discrimination (low rhyme errors and high Benton errors) constituted a minority of those with one and two left handed siblings but almost a quarter of those with no left handed siblings. The group with no specific deficit included a small percentage of individuals with two left handed siblings and a large percentage with few left handed siblings. These findings for relatives handedness support the hypothesis of a genetic influence on phonological processing as those individuals with two left handed siblings would be expected to be unlikely to possess a copy of the hypothesized rs+ gene. It is clear in figure 6.6 that this group alone includes a majority (64%) with poor nonword rhyme but good perception while the other two groups (with few left handed siblings) include majorities with no phonological problem. It is also worth noting that the majority in the two left handed siblings group, at 64%, is the largest majority of the three.

These findings for relatives handedness are as would be expected if the specific deficits examined were influenced by a genetic factor which also had an influence upon handedness.

General Discussion.

A statistically significant interaction between two different types of phonological processing and hand skill was found in this experiment. As expected from predictions of the RS Theory individuals with difficulties on a task of nonword rhyme decision were found more often to the left of the continuum of handedness than those without.

Conversely a group with no problems with nonword rhyme decision were found in the position on the continuum of handedness which would be expected to include a majority of individuals with the typical shift to dextrality. In contrast those with a deficit in phoneme discrimination were surprizingly found more often to the right for handedness, in the position occupied by those with no difficulties with nonword rhyme decision.

Although not statistically significant when hand preference was examined the sub-groups that are predicted, by the RS Theory, to lack the rs+ gene demonstrated specific nonword rhyme deficits while smaller specific difficulties in discrimination were found in the sub-groups that are expected to possess the rs+ gene (and so be shifted to dextrality in handedness).

These results for nonword rhyme decision were in the direction predicted by the RS Theory while those for phoneme discrimination were in the opposite direction to expectations. This interesting result needed further investigation. Both analyses revealed the predicted specific deficits in nonword rhyme ability, in those without the typical shift to dextrality, together with the surprizing specific deficits in phonological perception in those who are shifted to the right.

A further analysis examined the handedness and familial handedness of those individuals with differing specific phonological deficits. The three dissociation groups varied as expected in their own handedness but there was no statistical significance. Those with specific rhyme deficits were found in all hand preference sub-groups, as would be expected for a group with no bias to dextrality. In contrast those with specific difficulties in phonological discrimination were found only in the four right handed sub-groups and the left handed group which is most shifted to dextrality. This is as would be expected when predicting from earlier findings for a group with a bias to dextrality.

The RS theory is a genetic theory so variations in the handedness of individuals with specific deficits which are influenced by the rs+ gene should be reflected in variations in handedness amongst their relatives. Those with deficits in rhyme processing (phonological awareness) who were more to the left of the continuum of handedness were expected to have most relatives who were left handed. Conversely, those with deficits of phoneme discrimination who were to the dextral end of the continuum were expected to have least left handed relatives. This is precisely what was found with the groups varying in maternal, paternal and sibling handedness. Each of these analyses were statistically significant (with siblings highly significant) but several violated the assumptions of chi-square for expected frequencies of less than five. Those with specific rhyme deficits included the highest percentage of left handed fathers and left handed siblings and constituted the majority of those with two left handed siblings. In contrast those with specific difficulties in phonological discrimination included the lowest percentage of left handed mothers, fathers and siblings. These effects are discussed in greater detail in the final chapter.

The RS theory predicts that individuals with phonological deficits are likely to be found in those who lack the typical bias to dextrality due to absence of the hypothesized rs+ gene. Until now the specific type of phonological deficit which is involved has not been identified so any, or even all, aspects of phonological processing could be implicated. Different specific deficits are predicted by the RS theory to exist at both ends of the continuum of handedness. Until now it had been expected that risks to any phonological processing would be greatest at the left of the continuum of hand skill but this new finding opened up the possibility that there could be a risk to different specific phonological processes at each end of the handedness continuum. These interesting, and in the case of phoneme discrimination, surprizing results, found in a large and unselected sample of undergraduates, led to another experiment. This used individually presented tasks in order to identify, more clearly in undergraduates, difficulties in various components of phonological processing.

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Chapter 7

Two Investigations of Components of Phonological Processing in Selected Undergraduates with Individual Tests of Phonology

This chapter describes two factor analyses on tests given individually to undergraduate volunteers over three years. The first factor analysis included data from a common set of tests completed by all subjects and the second included the same data plus more from tasks completed only in the latter two years. Several of the phonological tasks, in this experiment, required the recording of individual responses (eg. spoonerism production, auditory acronym production) which could not be achieved in a group situation. The project was run over three years in order to collect approximately equal sized groups of first year undergraduates with different hand preferences (pure right, mixed right and pure plus mixed left).

Introduction.

The major question for investigation in this chapter was what components of phonological processing can be identified from a new sample of undergraduates and which of these phonological processes are associated with ear advantage and/or handedness? Annett (1985) has predicted an association between poor phonological processing and reduced dextrality and this has been supported by earlier analyses in this thesis and elsewhere. However, the problem of what specific aspects of phonological processing are affected has not previously been addressed. The last chapter reported evidence, from an unselected sample, in support of an association between two phonological processes (rhyme decision and phonological discrimination) and handedness. As predicted rhyme decision (or phonological awareness) was associated with reduced dextrality while unexpectedly phonological discrimination was associated with dextrality. Consequently this next experiment included further tasks of phonological processing in the expectation that other aspects of processing, which might or might not be associated with handedness, would be identified. Some of these tasks required individual presentation as it was necessary to record individual responses. Tests of rhyme decision and phonological discrimination were also included to test the reliability of the findings in the previous experiment.

This experiment, like Annett (1991a), used a dichotic listening technique to study lateralized information processing. Kimura (1961) was the first to use the dichotic listening technique to show a relationship with hemisphere asymmetry for speech. It is a relatively simple non-invasive task which is useful for examining hemisphere asymmetry in normal samples but cannot be used, with confidence, to determine the cerebral speech hemisphere of individuals (Kimura, 1961, 1967; Bryden, 1982). When verbal auditory stimuli are presented dichotically to normal subjects the average result is an advantage for the right ear (REA). It is generally accepted, and well supported by studies at Haskins laboratory, that most normal subjects have right ear advantage (REA).

The usual explanation for this REA is that the contralateral auditory pathways suppress the ipsilateral pathways. This gives preference to right ear input en route to the left hemisphere, which in the majority of individuals supports language (Kimura, 1967; Sparks & Geschwind, 1968; Eslinger & Damasio, 1988). In most people, this suppression forces auditory input to the left ear to be transmitted through the corpus callosum before it can be processed. It has been suggested that this has two effects - it postpones the arrival of the left ear signal at the language centres, in the left temporal lobe, and at the same time it degrades the signal (Springer & Deutsch, 1990).

Kinsbourne (1970) gave a different (attentional) explanation for the REA. He suggested that anticipation of a verbal stimulus alerts the left hemisphere to be ready to process the stimulus. Attention has been found to play a part in dichotic listening. The same dichotic stimuli has been found to give rise to a REA and a LEA (left ear advantage) depending on whether the subject *expected* a verbal or a nonverbal stimulus (Spellacy & Blumstein, 1970). It seems unlikely however that attention alone explains the phenomenon as REA has been found in a subject who was incapable of directing his attention to the left or the right ear (Hugdahl, Wester & Asbjornsen, 1991). In addition if attentional mechanisms were the only relevant factors then it would not be expected that both hemispheres could be activated at the same time. However this has been demonstrated (Goodglass & Calderon, 1977; Ley & Bryden, 1982) with a simultaneous REA being ellicited for verbal material and LEA for non-verbal material. Asbjornsen & Hugdahl (1995) suggest that attention exerts a modulating influence on dichotic listening by suppressing the ipsilateral input from the non-attended channel. The input from the non-attended ear, to the left temporal cortex, is then reduced to that which has crossed the corpus callosum.

In general it appears that the basic events of dichotic listening can be accounted for by a modified structural model which also takes into account the effects of directed attention (Geffen & Quin, 1984). Despite this controversy many studies have employed dichotic listening, with verbal stimuli, when identifying left hemisphere phonetic processing (Schwartz & Tallal, 1980). The validity of the technique has been investigated by some studies which have assessed hemisphere speech side with alternative methods and then compared results with assessment by dichotic listening. These studies have confirmed an association but not a direct link. Annett (1991a) describes three studies, Geffen & Caudrey (1981), Strauss, Gaddes and Wada (1987) and Zatorre (1989), which have used different forms of the dichotic task. Despite differences, in both method and types of subject, the proportions with LEA were consistent (21-30%) and compared with normal samples (Lake & Bryden, 1976). Over all three studies the proportion with LEA increased from 9% in subjects with left hemisphere speech, through 46% in those with bilateral speech to 67% in those with right hemisphere speech. Annett inferred from these studies that subjects with LEA include a higher proportion with atypical speech than those with REA.

Annett (1991a) combined the three studies and, accepting that the groups of subjects were small, specific and included different proportions, she showed that the combined data corresponded with predictions of the RS theory that ear advantage and speech side are determined by chance in atypical circumstances. This was illustrated by making several points about the combined data. Initially, it was demonstrated that amongst the subjects with LEA, 46.6% (approximately half) had right hemisphere speech. Secondly, she showed that the distribution of left, bilateral and right hemisphere speech (67%, 22% and 11%) in the combined studies closely paralleled the asymmetries of the planum temporale (65% left larger, 24% equal and 11% right larger) found by Geschwind & Levitsky (1968). Thirdly close to half (46.6%) of the right hemisphere speakers showed LEA, as would be expected from predictions of the RS theory. Combining bilateral and right hemisphere speakers (atypical speech) approximately half of the subjects (53%) had LEA. Finally she demonstrated that the distribution of left, bilateral and right hemisphere speech among the 45 subjects with LEA was 12, 19 and 14 approximately as would be expected for a random distribution.

The apparent correlation between ear advantage and cerebral speech, seen in the combined studies above, relies on the majority of people who possess both left sided speech and REA and without this large group the relationship between EA and speech side is probably random. Annett stated that it is impossible to *know* how many of the cases with left sided speech and REA also carry the rs+ gene (and consequently the bias to the left hemisphere for speech) and how many do not possess the gene but have this arrangement by chance. 'Bilateral specialization' in left handers has been suggested to explain evidence that aspects of speech and abilities which are strongly lateralized in right handers are also more weakly lateralized to the same side in left handers or mixed handers (Annett, 1982; Wexler & Halwes, 1983). However Annett suggests that the lack of significant differences in studies of cerebral specialization can be explained by a chance distribution of left, right and bilateral speakers. The RS theory predicts that hand preference and speech side are *independent in atypical cases* (so the use of handedness as a measure of speech hemisphere is misleading) and the major point is that all asymmetries, including speech side and DL, are expected to occur by chance except for those in individuals who possess at least one copy of the rs+ gene.

It has been suggested by Annett (1991a) that the laterality of auditory perception and production could be independent when the rs+ gene (which, for the majority, encourages their proximity in the left hemisphere) is absent. Such separate hemispheric representation has been found, using MRI, by Sakuri, Kurisaki, Takeda, Iwata et Al. (1992) who reported a case of dissociated aphasia (language production occurring in the left Broca's area and language comprehension occurring in the right Wernicke's area). Separate hemispheric position for handedness, speech output (and/or comprehension) in left handers is also suggested by Naeser & Borod (1986) and Alexander, Fischette & Fisher (1989) who reported that right handers with right hemisphere speech included 'anomalous' and mirror image representations. These studies support the possibility of independent lateralisation in atypical cases.

This experiment, like Annett (1991a), used a spoonerism task to measure phonological difficulties. The advantage of a spoonerism task (Perin, 1983) for testing phoneme segmentation is that it demands a more complex form of manipulation than the segmentation task used, in earlier chapters, for schoolchildren. Consequently this makes it more suitable for undergraduates. Creating spoonerisms from words spoken by an experimenter makes greater demands on phonological processing abilities than would a simple segmentation task. Two segmentations must be made, more items must be stored in auditory memory and a further process of attaching the correct phonemes is added before a new articulatory code can be set up. The task involves several stages of phonological processing. Successful accomplishment involves correctly perceiving the phonemes, accurately segmenting the initial phonemes from each word, storing both initial phonemes and both word endings in auditory memory while transposing the initial phonemes, attaching the initial phonemes to the appropriate word endings and finally assembling a new code for articulation. Problems with one, all or any combination of these processes would reflect a phonological deficit and is likely to be manifested in errors or hesitations when attempting to give an answer. Consequently errors and hesitations were used in this experiment as a measure of difficulty.

The first question for investigation in this chapter was to see what components of phonological processing could be identified from undergraduates. Secondly, it was expected that groups with differing ear advantage (LEA, REA and LE=RE) on a verbal dichotic listening task could also vary in ability in at least one type of phonological processing (and as a consequence their mean factor scores would vary). Thirdly, it was predicted that some or all of the phonological factors identified would be associated with handedness. From the results of the previous experiment it was expected that difficulties with phonological awareness would be associated with reduced dextrality and problems with phonological discrimination (or perception) would be associated with strong dextrality.

Further tasks were added to the basic core of tests in years 2 and 3 as they were expected to tap more specific phonological processing capabilities. The Benton Test of Phoneme Discrimination was expected to measure phoneme discrimination of speech (and perception or input), nonword repetition was expected to tap phonological production (or output) and the digit span task was anticipated to measure phonological memory. Consequently it was hoped that they would separate phonological processing into individual factors of phonological input, output and memory which could then be tested for an association with ear advantage and handedness as above. It was also expected that any phonological factors identified in the first factor analysis would predict at least one of these more specific phonological tasks.

Method.

All tasks were administered individually to undergraduate subjects and all relevant tests are described below.

Participants.

In total 123 undergraduates (68 females and 55 males) were recruited to give 3 approximately equal groups of 38 pure right handers, 44 mixed right handers and 41 pure + mixed left handers. They were all first year university students, between the ages of 18 and 43 years (mean age 20.9 yrs., S.D. 5.75 yrs.), who volunteered to take part. Hand preference groups were established from the 12 actions specified in the Annett Hand Preference Questionnaire (Annett, 1970).

All subjects took a common set of tests (a hearing test, spoonerisms, auditory acronymns, dichotic listening and nonword rhyme decision) and 64 of these participants also took additional tests (nonword repetition, digit span forwards and Benton phoneme discrimination).

Most subjects (118) came from Leicester University with five coming from other universities (recruited from personal contacts). Before analysis data from one participant, who was profoundly deaf, and from 8 subjects whose first language was not English were removed.

Year 1 - 59 undergraduates (34 females and 25 males, mean age 20.0 yrs., S.D. 4.2 yrs., range 18-43 yrs.) took part in the basic tests (tasks 3.1 - 3.8).

Years 2 and 3 - 64 undergraduates (34 females, 30 males, mean age 21.8 yrs., S.D. 6.9 yrs., range 18-53 yrs) took the basic tests plus additional tasks (tests 3.9 - 3.11) introduced in years 2 and 3.

Design.

In order to increase the number of left handed subjects in the sample this study was run over three years with the aim of collecting three approximately equal groups of participants with different hand preferences (pure right, mixed right and pure plus mixed left). Consequently the sample was not distributed normally. The first step, before analysis, was to screen the whole sample for hearing problems and exclude any with hearing deficits or whose first language was not English.

The main purpose of these analyses was to identify factors of phonological processing in undergraduates and to examine them in the light of the RS Theory. Both analyses proceeded in three stages as follows.

a) Can factors of phonological processing be identified?

b) Are these factors associated with ear advantage for dichotic listening?

c) Are they associated with handedness?

Procedure. Tasks 1-8 (laterality tasks of hand preference and handskill, a hearing test, phonological tasks of spoonerisms, auditory acronyms and non-word rhyme decision and a task of dichotic listening) were presented over all three years of data collection. However, the more specific phonological tasks of digit span, phoneme discrimination and non-word repetition were presented only in the latter two years. In each case subjects were tested individually in a quiet room and speech tests preceded the dichotic listening task. Details of all relevant tasks are provided below.

Basic Core of Tests (presented in all three years).

Data from laterality measures were available, for most subjects in years 1 and 2, from an earlier laboratory practical. This was unavailable for subjects in year 3 so the experimenter (PS), individually, observed hand preference and timed hand skill for moving pegs. One subject had hand preference and hand skill measures taken after the speech and dichotic listening tasks.

3.1: Annett Hand Preference Sub-group (laterality)

The hand used to perform the 12 items of the Annett Hand Preference Questionnaire was observed and noted by the experimenter. See chapter 3 and appendix K for more details.

3.2: Peg Board Handskill. (laterality)

Handskill was measured by the Annett pegboard task (Annett, 1970). The difference between the hands in time as a proportion of total time taken was calculated as ((L-R time)/(L+R time))*100 = R-L%. See chapter 3 and appendix U for further details.

3.3: Family handedness (laterality)

Data on family handedness was collected with subjects completing family trees of hand preference, where this was known. See chapter 3 and appendix O for more details.

3.4: Hearing Test. (auditory)

All subjects were tested, in both ears, for auditory sensitivity using a Kamplex diagnostic audiometer AD17. Tones of varying decibels (i.e. -10 to 70 dB) were delivered over a range of frequencies (250 - 8000 Hz). Subjects with greater than 10 decibels difference between their ears were excluded from analyses involving dichotic listening.

3.5: Spoonerisms (Perin, 1983) (phonological)

Subjects were asked to create a deliberate spoonerism using two words spoken by the experimenter. The task was to repeat the words but with the initial phonemes transposed. The method was as described by Perin (1983) and used by Annett (1991a). Each subject was individually tested and tape recorded, (by permission), so that responses could be checked later. The task was explained by giving three training examples ("key chain", "bones and joints" and "windmill") followed by three practice items ("David Bowie", "Talking Heads" and "Fatal Charm'). Subjects who had problems with these practice items were allowed to repeat the training if required. The main experiment consisted of 18 names of popular musicians which were expected to be reasonably familiar to most of the subjects.

A pause, before replying, of greater than 2 seconds was scored as a hesitation and one greater than 5 seconds was counted as an error. Errors were also counted when the exchange of phonemes was incorrect. In those cases where an error and a hesitation ocurred together only one error was scored. A hesitation of more than 2 seconds between the two words of the spoonerism reply was recorded as a mid-hesitation.The wordlist and instructions can be found in appendix R.

3.6: Auditory Acronyms (Wilding, 1990) (phonological)

An auditory acronym task (Wilding, 1990) based on an earlier study of Campbell and Butterworth (1985) was used. The task involved forming a new word from the initial sounds of three words spoken by the experimenter. 18 word triplets devised by Wilding (1990) were presented orally and different responses were possible depending upon whether initial sounds, or initial letters, were deleted and combined (e.g. "pen - owl - tyre" gives "pot" or "pout"). The task was explained and two training examples were given ("bad - emu - tin" yielding "beat" and "fill - ice - tea" yeilding "fight". These were followed with two practice items ("pen - owl - tyre" giving "pout" and "foul - ear - dip" giving "feed") and feedback was provided with the instruction that "pot" and "fed" were incorrect. All responses were recorded manually by the experimenter and only words formed from the initial *sounds* were scored as correct. Those formed from initial letters were scored as orthographic errors. Hesitations of longer than 6 seconds were noted. See appendix S for wordlist and instructions.

<u>3.7: Rhyming Nonword Decision Task.</u> (phonological)

A printed list (from Besner, Davies and Daniels, 1981) of 20 pairs of pronounceable nonsense words was presented individually. Rhyming pairs (n=10) were to be ticked while non-rhyming pairs (n=10) were to be crossed. Two examples (one rhyming "swoin'/ "toyne" and one not "quoz"/"fint") were used to explain the task and subjects were asked to work as quickly as possible but not to make any sound. Errors and time to completion were recorded by the experimenter. See appendix P for wordlist and instructions.

<u>3.8: Dichotic Listening.</u> (auditory)

Subjects listened, through headphones, to pairs of digits (1-9) which arrived simultaneously, one to each ear, at intervals of 150 msecs. When a "one" or a "nine" was heard (in either ear) subjects were instructed to press a response button which was held in his/her preferred hand. These target stimuli were selected as they have similar sound envelopes (Morton, Marcus and Frankish, 1976). The digits were presented by a digitised female voice on a Racal two channel tape recorder. An IBM compatible PC was used to run the experiment, control the tape recorder, time and record responses, errors and false positives (if a response was made when any other digit, not a "nine" or a "one", was spoken). The main experiment was preceded by 10 practice trials after which subjects were asked if they required more practice. If more was requested the 10 original practice trials were repeated until the subject felt confident to continue with the main experiment. This consisted of 100 trials of pairs of digits with target "ones" and "nines" occurring on 20 occasions in (quasi-)random order although at no time did they occur simultaneously at each ear. The 100 trials were then repeated with the headphones reversed to compensate for any inequalities in the two channels. In total the subject heard 200 pairs of digits with 40 target "ones" and "nines" occurring at each ear. Analyses were based on targets missed at each ear.

Additional Tasks (presented only in years 2 and 3).

The tasks, described below, were presented only in the second and third years of testing.

3.9: Digit Span (digits forward only). (phonology.)

Digits backwards were not presented due to constraints of time and concern that this aspect of the task is particularly likely to involve components of memory which are not auditory. Digits forward were presented singly and as in WAIS-R. If a subject failed both trials of any item the test was immediately discontinued. One mark was scored for each digit list recalled correctly with a maximum score of 16 marks.

3.10: Phoneme Discrimination. (phonology.)

The Benton phoneme discrimination test was presented individually, in a quiet room, and by tape recorder. In all other respects the procedure was identical to the phoneme discrimination task described in the previous chapter. The test consists of 30 tape recorded pairs of nonsense words spoken by an adult male and a decision had to be made as to whether each pair of nonwords was exactly the same or different. One mark was scored for each error whether the stimuli was "same" or "different". See appendix Q for the Benton nonword list.

3.11: Nonword Repetition. (phonology)

Ten multi-syllabyllic nonwords, containing consonant clusters (taken from Campbell and Butterworth, 1985, see appendix T) were presented auditorily by the experimenter. The subject repeated each nonword immediately after it was spoken and only repetitions which were entirely accurate were allowed. Inaccurate responses were scored as errors.

EXPERIMENT 8

Factor Analysis of the common set of 10 tests completed by all participants.
The purpose of this analysis was to distinguish types of phonological processing in a sample of undergraduates which included a raised proportion of left handers. Error scores from the spoonerism and auditory acronym tasks were entered into an SPSS principal-components varimax analysis together with Spoonerism hesitations and mid-hesitations. Errors and reaction times from the dichotic listening and non-word rhyme decision tasks were also included.

Results

Table 7.0 gives the means, std deviations and ranges of each variable for the 114 participants in the analysis and table 7.1 gives the factor loadings of all variables.

Table 7.0: Variable means and std deviations for the 114 cases in the analysis

Variable	Mean	Std Dev	Range	Min-max.
Spooner Error	1.51	2.23	18	0 - 18
Spooner Hesitation	2.17	3.1	18	0 - 18
Spooner Mid. Hes	1.91	2.79	18	0 - 18
Aud. Acronym Err	4.75	4.60	18	0 - 18
Dichotic R Time	641.27	104.43	745	447-1192
Dichotic L Time	640.39	86.95	381	474-855
Dichotic L Errors	2.49	2.83	13	0 - 13
Dichotic R Errors	1.87	1.89	9	0 - 9
Nonword Rhyme Err	0.57	0.87	6	0 - 6
Nonword Rhyme Time	40.97	13.56	86	24 - 110
N	114			

An SPSS principal-components analysis identified three factors with 4 varimax iterations and factor loadings of all variables are shown in table 7.1 below. See the first factor analysis in chapter 5 for a discussion concerning the acceptance of factors.

Table 7.1: Factor Loadings.

	Factor 1	Factor 2	Factor 3
Spooner Error	.86249 *		
Spooner Hesitation	.86834 *	.05805	
Spooner Mid. Hes	.71732 *		
Aud. Acronym Err	.81718 *	.07511	.17899
Dichotic R Time	-.06618	.91494 *	-.08607
Dichotic L Time		.88854 *	-.05304
Dichotic L Errors		.81628 *	.11085
Dichotic R Errors	.11248	.54978 *	.28102
Nonword Rhyme Err		-.08547	.88272 *
Nonword Rhyme Time	.28941	.26953	.62359 *
Eigenvalues	2.98992	2.65224	1.14752
Total % Variance.	29.9%	26.5%	11.5%

* a factor loading of greater than 0.6

Factor 1 Factor 1 loaded strongly on spoonerism errors, spoonerism hesitations, mid hesitations and auditory acronym errors. All of these were measures of articulatory response to an auditorily presented segmentation task so this factor was labelled phonological production /segmentation.

Factor 2 Factor 2 loaded highly on right and left ear dichotic reaction time, left ear errors and less strongly on right ear errors suggesting the name dichotic listening for this factor.

Factor 3 Factor 3 loaded strongly on nonword rhyme errors and nonword rhyme time and as a consequence was labelled rhyme awareness.

Discussion

The factor analysis was an SPSS principal components analysis with Varimax rotations. This results in orthogonal factors which cannot correlate so they can be used for regression analysis. Oblique factors were also examined but were found to vary little from orthogonal.

This analysis resulted in three factors which were labelled (1) phonological production /segmentation, (2) dichotic listening and (3) rhyme awareness /phonological awareness. Factor 1 loaded strongly on three of the Spoonerism measures (errors, hesitations and mid hesitations) together with auditory acronym errors. All of these involved articulating responses to an auditorily presented segmentation task so the factor was labelled phonological production /segmentation. The third factor loaded strongly on two measures of nonword rhyme (errors and time). Rhyme decision tasks are often used in the literature to measure phonological awareness (the ability to reflect explicitly on the sound structure of spoken words) so the factor was named rhyme /phonological awareness. Factor 2 loaded clearly on the four measures of dichotic listening (right and left ear reaction times plus left and right ear errors) so this factor was named dichotic listening. This separation of phonological processing into two factors of phonological production/segmentation and rhyme awareness supported findings of Muter, Hulme, Snowling and Taylor (1997) who identified two relatively independent factors of rhyme and segmentation from a battery of tests measuring phonological skills in pre-readers.

Dichotic Listening, Phonological Processing and Handedness.

The purpose of this analysis was to examine whether groups with differing ear advantage on the dichotic listening task also differed for either of the two phonological factors (factors 1 and/or 3). In order to do this the mean factor scores of groups with differing ear advantage (REA, RE=LE and LEA) were compared. It was expected that difficulties with at least one of the phonological factors could be associated with atypical ear advantage. Two of the factors appeared to be phonological (phonological production/ segmentation and rhyme /phonological awareness) so it was possible that either or both could be associated with ear advantage for verbal data.

To investigate any association with ear advantage SPSS was used to calculate two factor scores for each individual (one for each phonological factor) and to compare, by oneway analysis of variance, the mean factor scores of groups with varying ear advantage (REA, RE=LE and LEA). Contrasts where appropriate were Least Significant Difference. As the factor scores were calculated from error scores, high factor scores signify poor ability and low factor scores indicate good ability on any factor.

Results

Thirty five subjects (31%) made equal numbers of errors at each ear, on the dichotic listening task, so no advantage could be calculated for any side. Forty eight participants had right ear advantage (REA, 42%) and 31 had left ear advantage (LEA, 27%). Table 7.2 gives the mean left and right ear errors (plus std. devs. and ranges) of the whole sample plus those for each ear advantage group. Mean factor scores for each group may be found in table 7.3

Table 7.2: Mean L and R ear errors for those with LEA and REA on a task of Dichotic Listening

Ear Advantage	Mean R ear errs	S.D.	Range	Min-max.	N
REA	1.65	1.80	6	1 - 7	48
LEA	3.03	2.04	8	1 - 9	31
LE=RE	1.14	1.35	5	0 - 5	35
Whole Population	1.87	1.89	9	0 - 9	114
Ear Advantage	**Mean L ear errs**	**S.D.**	**Range**	**Min-max.**	**N**
REA	4.31	3.25	12	1 - 13	48
LEA	1.19	1.56	7	0 - 7	31
LE=RE	1.14	1.35	5	0 - 5	35
Whole Population	2.49	2.83	13	0 - 13	114

Table 7.3: Mean Phonological Factor Scores of the Three Ear Advantage Groups.

	REA		LEA		RE=LE	
	Mean	**(SD)**	**Mean**	**(SD)**	**Mean**	**(SD)**
Phon. Prod.	-0.142	(0.93)	0.071	(0.81)	0.136	(1.23)
Phon Aw. (Rhyme)	-0.046	(0.81)	0.042	(1.12)	0.103	(1.15)

Examination of the mean factor scores, in table 7.3, show trends for the RE=LE group to have relatively poor scores on both factors but an analysis of variance found no significant overall effects for either phonological factor and dichotic listening group (*phonological production/segmentation*, F (2, 112)= 0.873, $p > 0.1$; *rhyme/phonological awareness*, F (2, 112)= 0.252, $p > 0.1$).

Discussion

The group with the atypical pattern of equal left and right ear errors appeared to perform relatively poorly in comparison to the other groups on both aspects of phonological processing (rhyme/awareness and production/segmentation) while the REA group tended to be relatively good. However, although in the direction consistent with predictions of the RS Theory, trends were not statistically significant .

Three Factors and Writing Hand.

Annett has suggested that risks for phonological processing deficits are associated with a reduced bias to dextrality but she has not specified what type of phonology is involved. This analysis investigated whether any of the factors, identified above, was associated with handedness. In order to do this groups were identified for each of the two phonological factors (phonological production/segmentation and rhyme/phonological awareness). One group had high factor scores (greater than 1 and so poor ability) while the other had relatively low factor scores (1 and lower and so average or good ability). SPSS chi-square was used to compare the number of left writers in these groups.

Results

The sample was selected to include a higher than normal proportion of left writers (38 out of 114, approximately 33%) so percentages are expected to be high in all groups. Table 7.4 gives the number of left handed writers in groups with relatively good or poor ability in the two phonological factors (i.e. factor scores greater than 1 versus 1 and lower). Figure 7.1illustrates the percentages of left writers in these groups with varying ability in phonological production and phonological awareness.

Table 7.4: Left Handed Writers in Gps. with Varying Phonological Factor Scores

Factor		L. Handed Writers	(%)	N.
Phonological Production/Segmentation				
	Poor (>1)	8	(57%)	14
	Good (=<1)	29	(29.3%)	99
Phonological Awareness				
	Poor (>1)	8	(50%)	16
	Good (=<1)	29	(29.9%)	97

The group with poor ability in phonological production/ segmentation included a majority of left writers. Fifty seven percent of the group with high phonological production/ segmentation factor scores (i.e. poor production/segmentation) were left handed in comparison to only 29.3% of the group with lower factor scores (i.e. relatively good production/segmentation). There were statistically significantly more left writers in the group with poor phonological production/ segmentation than in the group with relatively good ability (Chi-square (df 1) = 4.3199, p = 0.038, Fisher's Exact 0.041, both significant although one expected value was only just 5)

Fifty percent of the group with high rhyme phonological awareness factor scores (and poor ability) were left handed in comparison to only 29.9% of the group with lower factor scores (and relatively good ability) but this was not statistically significant (Chi-square (1) = 2.520, p = 0.11).

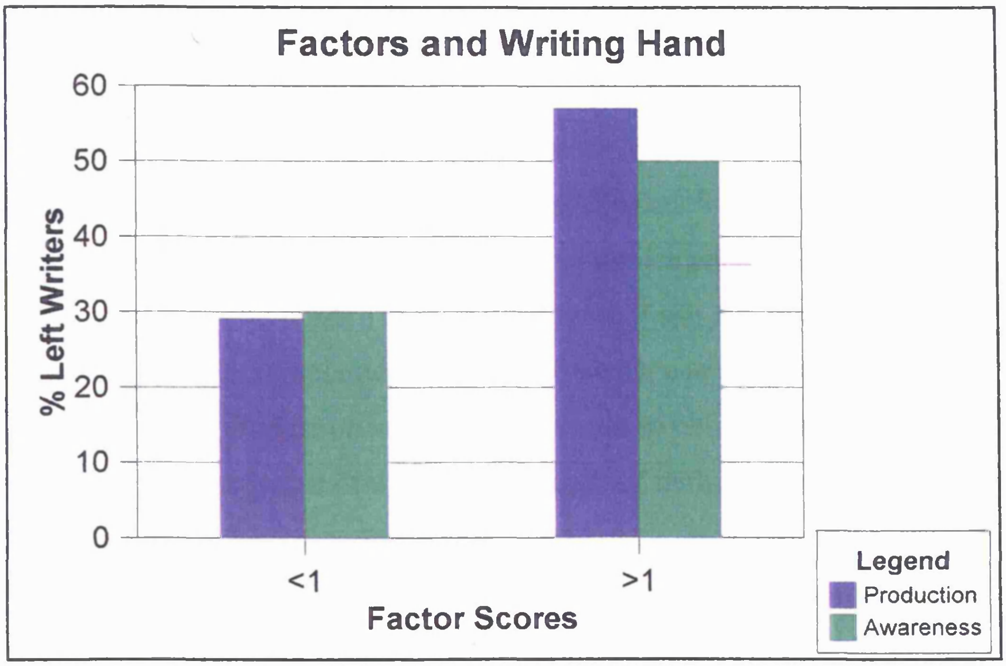

Figure 7.1: Percentages of left writers in groups with better ability (factor scores of < 1) and worse ability (factor scores of >1) in phonological production/ segmentation or phonological awareness.

Discussion

An association, in the expected direction,was demonstrated between phonological processing and handedness with poor phonological production/segmentation being associated with reduced dextrality. Statistically significant differences were found so that those with relatively poor phonological production/ segmentation included many left writers and those with better abilities included a lower proportion of left writers. In addition more left writers were found amongst those with relatively poor rhyme/phonological awareness than amongst those with relatively good ability but the difference was not statistically significant. An association between hand preference and phonological production/segmentation was clearly demonstrasted with poor phonological processing being associated with reduced dextrality as would be expected from predictions of the RS Theory.

EXPERIMENT 9

Factor analysis of 13 tests in 54 subjects

The second SPSS varimax factor analysis added data from the three additional tasks (nonword repetition, digit span forwards and Benton phoneme discrimination) to the common set of tasks used in the analysis above. It was anticipated that by this addition new factors which represented more specific components of phonological processing (i.e. perception, production and memory) would be obtained. As a consequence of including all tests (some of which were presented in the last two years of testing only) the number of subjects involved was reduced to 54. However, this was well within Kline's (1994) recommended guidelines for factor analyses (a minimum variable to subject ratio of 2:1).

The main purpose of this section was to identify more specific factors of phonological processing in undergraduates and to examine them in the light of the RS Theory so analysis again proceeded in stages as follows:

a) Can factors of phonological processing be identified?
b) Are these factors associated with ear advantage for dichotic listening?
c) Are they associated with handedness?

Results.

Table 7.5 gives the variable means, standard deviations and ranges for the 54 participants in this analysis.

An SPSS principal-components analysis identified five factors with 6 varimax iterations. Again the factors were orthogonal and by definition did not correlate. The factor loadings of all variables are listed in table 7.6.

Table 7.5: Variable means for the 54 cases in the analysis

Variable	Mean	Std Dev	Range	Min-max.
Spooner Error	1.76	2.24	9	0 - 9
Spooner Hesitation	1.91	2.53	11	0 - 11
Spooner Mid. Hes	1.79	2.01	8	0 - 8
Aud. Acronym Err	4.55	4.38	17	0 - 17
Dichotic R Time	626.96	109.49	545	447 - 992
Dichotic L Time	625.81	91.92	323	495 - 818
Dichotic L Errors	2.11	2.73	13	0 - 13
Dichotic R Errors	1.34	1.68	7	0 - 7
Nonword Rhyme Err	0.62	0.74	3	0 - 3
Nonword Rhyme Time	38.21	9.67	86	24 - 110
Digit span forwards	11.42	2.39	14	2 - 16
Benton discrim	2.02	1.43	6	0 - 6
Nonw repetition	1.59	1.55	5	0 - 5
N	54			

Table 7.6: Factor Loadings.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Spooner Error	.74159 *	-.19043	.41295		
Spoon Hesit.	.69353 *		.38442	-.19840	.12365
Sp. Mid. Hes	.35162	.07132	.61119 *	.23891	.38915
Aud. Acro. Err	.86755 *				-.16992
Dichotic R Time		.90199 *			.24536
Dichotic L Time	.16078	.86631 *		-.16722	.18882
Dichotic L Errors	-.14394	.86863 *	.13028	.19424	-.08468
Dichotic R Errors	.11248	.69572 *	.13940	-.10419	-.39011
Nonword Rhyme Err		.06342	.12834	.93405 *	
Nw. RhymeTime	.58357 *	.21408	.26378	.15202	.19324
Digit Span Fwd	-.17682	-.11194	-.90645 *		.11540
Benton Discrimin.					.81697 *
Nonword Repetition	.78406 *		-.11913	.38900	
Eigenvalues	3.625	2.930	1.292	1.046	1.016
Total % Variance.	27.9%	22.5%	9.9%	8.0%	7.8%

* loading of more than 0.6

<u>Factor 1</u> loaded highly on auditory acronym errors, nonword repetitions, spoonerism

errors plus hesitations, nonword rhyme time and less strongly on spoonerism mid-hesitations. Consequently it was labelled phonological production /segmentation.

Factor 2 loaded strongly on the 4 dichotic listening measures of left and right ear time and left and right ear errors so it was named dichotic listening as before.

Factor 3 loaded strongly on digit span and spooner mid-hesitations and less strongly on spoonerism errors and hesitations. It was therefore termed phonological memory.

Factor 4 loaded highly on nonword rhyme errors and much less strongly on nonword repetitions so it was labelled phonological awareness.

Factor 5 loaded highly on phoneme disrimination errors and weakly on spoonerism mid-hesitations, dichotic listening right errors negatively. It was therefore named phonological discrimination (or perception).

All of the five factors were accepted (using Klines criterion of the Cattell scree test, see discussion in the first factor analysis in chapter 5).

Discussion.

Five factors representing phonological production/segmentation, dichotic listening, phonological memory, rhyme (or phonological awareness) and phonological discrimination were identified.

The first factor loaded strongly on auditory acronym errors, nonword repetitions, spoonerism errors, hesitations and mid-hesitations plus nonword rhyme time which suggested the name phonological production/segmentation (or output) for this factor. Successful accomplishment of the auditory acronym, spoonerism and nonword repetition tasks all require the production of a new phonological code for articulation while the nonword rhyme decision task is expected to require the setting up of two new codes before a decision can be made. Consequently, most of these tasks appeared to measure different types of phonological production in auditorily presented speech tasks. However phonological segmentation would also be needed to successfully accomplish all of these tasks so it could not be ruled out as a name for this factor.

Factor two loaded strongly on all of the four measures of dichotic listening (right and left ear time and right and left ear errors) so this was clearly a factor of dichotic listening.

The third factor loaded strongly on digit span and spoonerism mid-hesitations plus less strongly on spoonerism errors and hesitations. This suggested the name 'auditory memory ' as both the digit span and the spoonerism tasks require auditory memory for successful completion. Digit span was designed primarily as a test of auditory memory. Spoonerism mid-hesitations involve a hesitation between responding with the first and the second part of the word couplet. Both parts of the couplet must be retained in auditory memory for the second part to be completed successfully without hesitation so a high score here could be expected to indicate a problem with auditory memory.

Factor four loaded highly on nonword rhyme errors and much less strongly on nonword repetitions (or output). The two measures of the nonword rhyme task (time and errors) were separated with the time taken to complete the task being explained more fully by factor 1 (phonological output). This new factor explained approximately 85% (0.93405 squared) of variance in nonword rhyme errors so it was labelled rhyme or phonological awareness. The secondary label was used as in the literature rhyme decision tasks are widely accepted as a good measure of phonological awareness.

This second factor analysis separated nonword rhyme times and nonword rhyme errors into two different factors of phonological output and phonological awareness. Nonword rhyme times had a loading of 0.58755 on the phonological output factor but below 0.05 on the new factor of phonological awareness. Consequently, approximately 34.5% of variance in nonword rhyme times is explained by phonological output (0.58755 squared and multiplied by 100) whereas a negligible amount is explained by this new factor of phonological awareness. As previously described the assembly of a new phonological output code is necessary for a nonword rhyme decision and the degree of difficulty found with this appears to be reflected in the time taken to do the task. The number of errors made on this task do not seem to reflect any problem with phonological output (a loading of less than 0.05 explains a negligible amount of the variance in errors) but form a separate factor (4) of rhyme, or phonological awareness, which explains approximately 85% of this variance.

Factor five loaded highly on phoneme disrimination errors and weakly on spooner mid-hesitations plus a weak negative loading on dichotic listening right errors. This suggested the name of phonological discrimination (perception or input) because right ear errors on the dichotic listening task are also a measure of phonological perception where the contra-lateral connection is dominant. As the majority of individuals are expected to have left hemisphere speech it would be anticipated that right ear errors would be more sensitive than left ear errors as an index of phonological perception. In addition it would be expected that mid-hesitations on the spooner task would be influenced by difficulties in perception although why mid-hesitations should be more affected than errors and hesitations is not clear.

Five factors and Ear Advantage

The previous analysis of factors and ear advantage was repeated using these 5 new factors. It was again expected, in the light of the RS theory, that at least one of the phonological factors would be associated with atypical ear advantage. Four of the factors were phonological (production /segmentation, memory, awareness and discrimination) so it was possible that any of these could be associated with ear advantage.

New factor scores were calculated, by SPSS, for each individual. As error scores were entered in the factor analyses those with positive scores are below average for any particular attribute and those with negative scores are above average. Groups with differing ear advantage (LEA, RE=LE and REA) were compared, by oneway SPSS

ANOVA, for mean factor scores. Again contrasts where appropriate were Least Significant Difference.

Results

Fifteen subjects had left ear advantage (LEA), 17 had equal right and left ear errors (RE=LE) while 21 had right ear advantage (REA). Table 7.7 gives the mean left and right ear errors (plus standard deviations and ranges) on the dichotic listening task and table 7.8 gives the mean factor scores (plus standard deviations) for each ear advantage group. Figure 7.2 illustrates the mean phonological awareness and phonological perception factor scores of the three groups with REA, LEA and RE=LE.

Table 7.7: Mean L and R ear errors of gps. with LEA and REA on a task of Dichotic Listening

Ear Advantage	Mean R ear errs.	S.D.	Range	Min-max.	N
REA	1.09	1.81	7	0 - 7	21
LEA	2.20	1.52	6	1 - 7	15
LE=RE	0.89	1.37	5	0 - 5	17
Whole Population	1.34	1.68	7	0 - 7	53

Ear Advantage	Mean L ear errs.	S.D.	Range	Min-max.	N
REA	3.90	3.25	12	1 - 13	21
LEA	1.00	1.51	6	0 - 6	15
LE=RE	0.89	1.37	5	0 - 5	17
Whole Population	2.11	2.73	13	0 - 13	53

Table 7.8: Mean Factor Scores of Groups with Varying Ear Advantage.

Factors.		REA	LEA	L=R	DF	F	P	Sig. Contrasts
Phon. Prod.	**Mean**	-0.135	0.061	0.113	2, 50	0.320	>0.1	
	(sd)	(0.92)	(0.93)	(1.18)				
Phon. Mem.	**Mean**	-0.003	-0.109	0.100	2, 50	0.169	>0.1	
	(sd)	(1.11)	(1.01)	(0.89)				
Phon. Aw.	**Mean**	0.134	-0.669	0.425	2, 50	6.074	0.004 **	1:2 *
	(sd)	(1.00)	(0.39)	(1.10)				3:2 *
Wted and Unwted Quad. Trends					*1*	*11.52*	*0.0014 **	
Phon. Perc.	**Mean**	0.325	-0.440	-0.013	2, 50	2.727	0.075	1:2 *
	(sd)	(0.99)	(1.13)	(0.77)				
Wted and Unwted Quad. Trends					*1*	*4.05*	*0.049 *	
N		21	15	17				

* Significant at the 0.05 level. ** Significant at the 0.01 level.

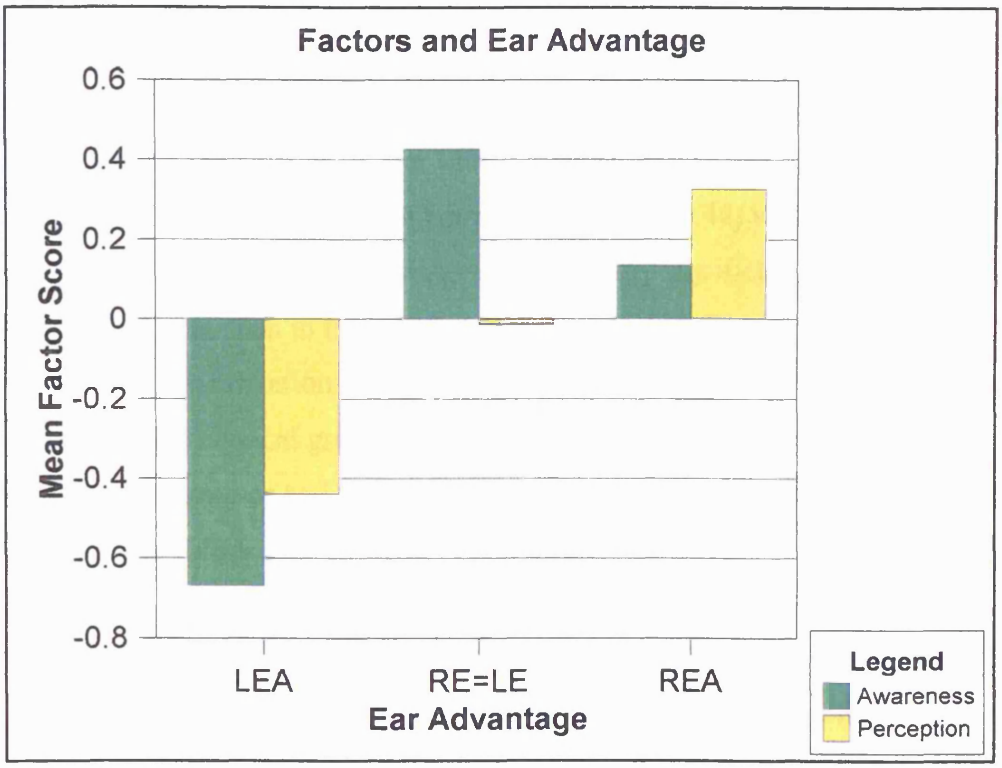

Figure 7.2: Mean phonological awareness and phonological perception factor scores of groups with LEA, LE=RE and REA on a dichotic listening task.

Phonological Awareness or Rhyme. Differences between the three groups in phonological awareness or rhyme were highly statistically significant (F (2, 50)= 6.074, p = 0.0044 with a significant quadratic trend (df 1), 11.527, p = 0.0014). The mean factor scores of the three groups varied so that those with no bias to either ear were associated with poor phonological awareness (RE=LE mean 0.425), those with the atypical pattern of LEA (mean -0.669) were superior to both other groups and those with REA (mean 0.134) were intermediate. Highly significant contrasts were found between those with LEA and REA (t (df 27.7)= 3.32, p = 0.003) and between those with LEA and LE=RE (t (df 20.47)= -3.82, p = 0.001). Levenes test for Homogeneity of variance was significant (4.565, df = 2, 50, p = 0.015) so separate variance figures are reported. The group with no strong lateralization to either hemisphere, for speech processing, was associated with poor phonological awareness, or rhyme awareness.

Phonological Perception. Between groups differences were non-significant trends for the phonological perception factor (F (2, 50)= 2.727, p = 0.075), but quadratic trends were significant ((df 1)= 405, p = 0.049). The group with the typical pattern, for dichotic listening, of REA (mean factor score 0.325) had poor phonological perception, those with the atypical pattern of LE=RE (mean factor score -0.13) were intermediate and those with the atypical LEA (mean factor score -0.44) were superior. A contrast between those with LEA and REA was statistically significant (t (df 34)= 2.16 , p = 0.038). It can be seen in figure 7.2 that the group with the typical pattern of left hemisphere lateralization for speech (REA) was poor at phonological perception while in contrast the atypical groups, which either lateralized to the right hemisphere for speech processing or had no strong lateralization to either hemisphere, displayed superior phonological perception.

Phonological Production /segmentation. The atypical group with equal R and L ear errors was poor at phonological production /segmentation (mean factor score: RE=LE 0.113) when compared with those with L or R ear advantage (mean factor score: LEA 0.061, REA -0.135) although there was no statistical significance (F (2, 50)= 0.320, p>0.1).

Phonological Memory. The atypical group with equal R and L ear errors had relatively poor phonological memories (mean factor score: RE=LE 0.100) when compared with those with L or R ear advantage (mean factor score: LEA -0.109, REA -0.0031). However differences between the groups did not differ statistically ($F(2, 50) = 0.169$, $p > 0.1$).

Discussion

Phonological awareness and phonological perception were both found to be statistically significantly different in the three ear advantage groups with highly significant differences in phonological awareness. As expected, the group with no strong lateralization to either hemisphere, for speech processing, was associated with poor phonological awareness. It has been argued by Annett that individuals with no strong lateralization to either hemisphere could have different aspects of phonological processing distributed at random between their two cerebral hemispheres. This could imply that they experience phonological problems due to the necessity of additional crossings of the corpus callosum *during* speech processing.

The atypical pattern of left ear advantage for dichotic listening was associated with superior phonological awareness (or rhyme) and phonological perception. It is possible that many individuals in this group had no disadvantage to the right hemisphere (as they did not possess the factor which causes speech processing to shift to the left hemisphere). If they did lack this factor they may also have no phonological disadvantage because, by chance, all their speech processes were assembled together in the right cerebral hemisphere. This could leave them with no more phonological problems than those with the typical REA but with additional superior right hemisphere abilities as they did not have the typical slight disadvantage to the right hemisphere hypothesized to cause the typical shift to the left hemisphere. The possibility of finding a group with these characteristics is likely to be higher in samples taken from undergraduate volunteers as these are a highly selected group which is not expected to include many individuals with major phonological problems.

Phonological discrimination was however poor in the group which appeared to have the typical pattern of left hemisphere lateralization for speech (REA) while those with no specific lateralization (LE=RE) and right hemisphere lateralization (LEA) were intermediate and superior, respectively. Could possession of the factor which Annett has proposed induces left hemisphere lateralization for speech (the rs+ gene) also be associated with a difficulty with phonological perception? If the rs+ gene slightly disadvantages the right cerebral hemisphere, as proposed by Annett, then possibly this affects aspects of phonological perception which are in the right hemisphere. If the rs+ gene is causing difficulties with phonological perception then the association between handedness and phonological perception which was found in the last chapter should be replicable in this sample too.

Phonological production and phonological memory were not statistically significantly associated with ear advantage although the atypical group with equal right and left ear advantage was relatively poor at both. However this could reflect the influence of phonological awareness on phonological production.

Five Factors and Handedness.

To investigate these interesting findings further the five factors (phonological production, dichotic listening, phonological memory, phonological awareness and phonological perception) were tested for an association with handedness. The numbers of left writers in groups with poor and good ability in each factor were compared by SPSS chi-square. To accomplish this two groups were identified for each factor as is shown on the following page.

1) poor ability - factor scores greater than 1,

2) good and average ability - factor scores of 1 and below.

Results

Left Handed Writers

Overall 20 (37%) of the 54 participants in the whole sample were left handed writers so percentages are expected to be high in all groups. Table 7.9 gives the number of left handed writers in the groups with average and above ability (factor scores of 1 and below) and below average ability (factor scores greater than 1) in phonological production /segmentation, awareness and perception. Figure 7.3 shows the corresponding percentages in each group.

Table 7.9: Left Handed Writers and Good and Poor Factor Scores

Factor		L. Handed Writers	(%)	N.
Phon Production/Segmentation **				
	Poor (>1)	8	(80%)	10
	Good (=<1)	11	(25.6%)	43
Dichotic Listening				
	Poor (>1)	1	(17%)	6
	Good (=<1)	18	(38%)	47
Phonological Memory				
	Poor (>1)	3	(33%)	9
	Good (=<1)	16	(36.4%)	44
Phon Awareness				
	Poor (>1)	4	(67%)	6
	Good(=<1)	15	(31.9%)	47
Phonological Perception *				
	Poor (>1)	0	(0%)	7
	Good (=<1)	19	(41.3%)	46

** highly statistically significant
* statistically significant

The group with poor phonological production (factor scores greater than 1) included a large majority of left writers in contrast to the group with good phonological production (factor scores of 1 and fewer). Eighty percent of those with high phonological production factor scores were left handed in comparison to only 25.6% of the group with lower factor scores. Chi-square was highly statistically significant (Chi-square (df 1) = 10.447, p = 0.001) as was the Fisher's Exact, (p= 0.002) but one value violated chi-square assumptions for expected frequencies of less than five..

The group with poor phonological awareness included a raised proportion of left writers in contrast to the group with good phonological awareness. Sixty seven percent of the group with poor phonological awareness were left handed in comparison to only 31.9% of the superior group (with lower factor scores). Chi-square was a non-significant trend (Chi-square (df 1) = 2.794, p = 0.095) although two values violated chi-square assumptions for expected frequencies of less than five.

The group with poor phonological perception included *no left writers* in contrast to the group with good phonological perception (and lower factor scores) which included 41.3% of left writers. Chi-square and Fisher's Exact were statistically significant (Chi-square (1) = 4.507, p = 0.034 and Fisher's Exact p = 0.035) although two values violated chi-square assumptions for expected frequencies of less than five.

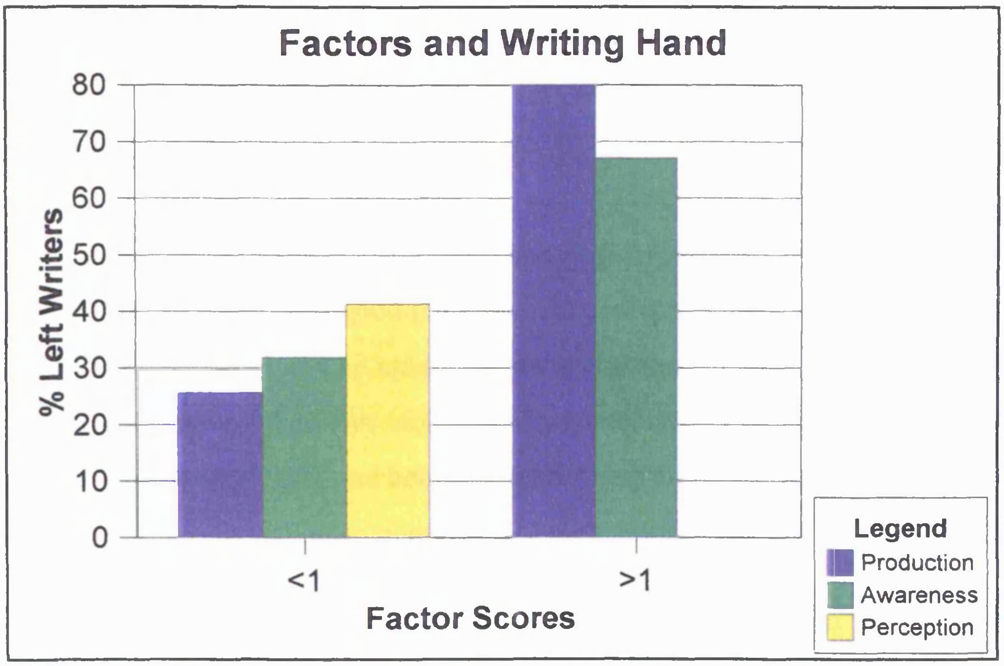

Figure 7.3: Percentages of left writers in groups with average and above ability (factor scores of < 1) and below average ability (factor scores of >1) in phonological production, awareness or perception.

Seventeen percent of the group with high dichotic listening factor scores were left handed in comparison to 38% of the group with lower factor scores but this was not statistically significant (Chi-square (1) = 1.083, $p > 0.1$). Thirty three percent of the group with poor phonological memory were left handed in comparison to 36.4% of the superior group (with lower factor scores) but this was also not statistically significant (Chi-square (1) = 0.030, $p > 0.1$).

Discussion

It must be remembered that these analyses used a sample of undergraduate participants which included a higher than normal percentage (approximately 37%) of left handed writers. Consequently percentages of left writers in all groups are higher than normal and the result for phonological perception is therefore particularly impressive.

As expected from predictions of the RS theory the majority of those with poor phonological production (80%) and phonological awareness (67%) were left writers in comparison to only 26% and 32% with good ability Chi square was statistically significant for phonological production and a non-significant trend for phonological awareness (although assumptions for expected frequencies of less than five were violated for both analyses).

In contrast *no individuals* with poor phonological perception wrote with their left hand while 41% of those with good phonological perception were left writers (also a statistically significant Chi-square, but with chi-square assumptions for expected frequencies of less than five violated). This association predicted from the results of the previous chapter, was found between handedness and phonological perception. In contrast to production poor phonological perception was associated with increased, not reduced, dextrality.

General Discussion

All findings reported in this chapter were from a sample of undergraduate participants which were selected to include a higher than normal percentage (approximately 37%) of left handed writers. This resulted in higher than normal percentages in all groups and consequently the result of the analysis for phonological perception is especially impressive.

The first factor analysis identified three factors of phonological production/segmentation, dichotic listening and rhyme/phonological awareness. Poor phonological production/segmentation was associated with an absence of shift to dextrality in handedness but the association with phonological awareness was not statistically significant.

Factor analysis two identified five factors of phonological production/segmentation, dichotic listening, phonological memory, phonological awareness and phonological perception. The atypical pattern of equal left and right ear errors for dichotic listening was associated with phonological awareness difficulties as was the atypical pattern of absence of shift to dextrality in handedness although the latter was only a non-significant trend. This supports predictions of the RS Theory for the existence of phonological difficulties amongst groups who lack the typical bias to the left hemisphere for speech processing and the typical shift to dextrality in handedness. The other atypical pattern of left ear advantage for dichotic listening was associated with good phonological awareness and phonological perception. This supports a further prediction of the RS Theory for the existence of a group that also lacks the typical bias for speech processing and shift for handedness. However this group by chance develops different aspects of speech processing together and so experiences no difficulties with phonological processing plus no right hemisphere deficits due to the presence of the factor which induces left hemisphere speech processing (the rs+ gene).

Undergraduates with problems of phoneme discrimination in this experiment were consistent with findings of the previous chapter in showing lateral bias in the typical direction. Even in this sample which included a raised number of left writers (approximately 37%) *no left writers* were found in the group with difficulties in phonological discrimination. The associations between problems with phonological discrimination and lateral bias (for dichotic listening and handedness) in the typical direction were as would be expected if the influence of the rs+ gene, which is proposed to cause the typical shift to left hemisphere speech processing, has a deleterious effect on phonological discrimination.

Neither phonological production/segmentation or phonological memory were found to be associated with ear advantage. However phonological production/segmentation and, more weakly, phonological awareness were associated with handedness so that those with poor production/segmentation or awareness included more left writers than those with average or good ability. However it is possible that this was caused by an indirect effect (already discussed) of phonological awareness on phonological production/segmentation.

Is poor phonological awareness or poor phonological production/segmentation associated with reduced dextrality (and absence of the rs+ gene) and poor phonological perception associated with increased dextrality (and presence of the rs+ gene)? Could phonological awareness or phonological production/segmentation be the phonological process for which the rs-- genotype is expected to be at risk and could minor phoneme perception problems be the disadvantage for the rs++ genotype? It is possible that the latter could possibly be part of a multi-sensory problem as proposed by Stein and Walsh (1997). These questions are discussed further in the following chapter.

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Chapter 8

Discussion

This chapter concludes the thesis by reviewing its contributions and implications together with a discussion of its limitations. The findings presented here have the potential to make contributions to developmental psychology, cognitive psychology and teaching practice. A number of suggestions for future research will also be made.

The Annett RS Theory predicts at least two types of difficulty with literacy that occur naturally as a result of individual differences in patterns of cerebral specialization for speech processing. The theory has proposed that these two types of difficulty could explain the considerable evidence for the existence of two types of dyslexia (e.g. Castles and Coltheart, 1993). Such individual differences are expected to be a part of normal development so it is also expected that the two types of difficulty will be found to a lesser extent in those who are not diagnosed as dyslexic.

This thesis has addressed the interesting question of what type of phonological deficit could be at risk in those who lack the rs+ gene (as predicted, by the RS Theory). Investigation of this initially involved testing, in a large population sample of school children, whether phonological difficulties could be found in the general population in those who are to the left of the continuum of handedness. Some evidence for this, which although not always statistically significant was consistent with previous research (e.g. Annett, 1991a; Annett 1992a), was found here in two experiments (of nonword spelling and real word segmentation) and was described in chapter three. Nonword spelling was used to screen an entire cohort of school children with a majority of the sample also completing the segmentation task. Consequently, these first two analyses supported earlier evidence that phonological deficits, in those with reduced dextrality, can be found in the general population. Annett, Eglinton & Smythe (1996) have used the phoneme segmentation task in their analysis of poor readers but the nonword-spelling test in this thesis has not been used in previous analyses.

Although not always statistically significant, it was shown in these first experiments that evidence for reduced dextrality in those with a phonological deficit increased after selection for ability (see figure 3.1, 3.2, 3.5 and 3.6). Even after using the strict criterion of a Bonferroni correction, the analyses for writing hand provided evidence that a purely "pathological" explanation is not enough to justify the existence of phonological deficits in this section of the population. The effects for phonological deficits were found in a population that had no evidence of developmental pathology. A much more plausible explanation, for the increasingly strong evidence of phonological deficits found in those with reduced dextrality, but good general ability, is provided by the hypothesis of a "specific disability" in those with otherwise normal development.

Furthermore, these first experiments demonstrated tentative support for the argument that these differences in phonology are due to the influence of a genetic mechanism. Although analyses were not statistically significant, the relatives of children with good or poor phonological processing abilities varied in handedness so that those with poor phonology had considerably more left handed relatives than those with average or good phonology (as is predicted by the RS Theory).

The next experiments, described in chapter 4, tested a further hypothesis of the RS Theory, that the shift to dextrality is both absent in those with weak phonological processing and strongly present in poor readers and poor spellers with good phonological processing. A summary of Annett, Eglinton and Smythe (1996), which examined poor readers, was described together with a new analysis, which examined poor spellers. Evidence was demonstrated here, from both poor readers and poor spellers, that phonological dyslexics, and poor spellers with phonological difficulties, are significantly less dextral than controls. Controls were also shown to be less dextral than non-phonological dyslexics, and poor spellers with good phonology.

Having demonstrated, in a sample with no evidence of developmental pathology, that poor readers and poor spellers with phonological problems are less dextral than those without such problems the next stage in the investigation was to attempt to identify what phonological processes might be at risk in those with reduced dextrality. A first factor analysis, described in chapter 5, used data from most of the original population sample and revealed two factors of verbal and non-verbal ability. A relationship with handedness was found for the verbal (but not the non-verbal) factor with, as expected, poor verbal ability being associated with reduced dextrality. As predictions of the RS Theory concern phonological processing further more specific phonological test data, which was available from the third year of testing, were added to the second factor analysis. This new analysis resulted in the identification of four factors of phonological production/segmentation, phonological memory, non-verbal processing and phonological discrimination. Both phonological production/segmentation and phonological memory were found to explain the variance in reading and spelling ability while non-verbal processing explained the variance in reading only. This evidence supported the hypothesis that phonological processing consists of separate component processes, of which some or all are necessary for the development of literacy. Muter, Hulme, Snowling and Taylor (1997) have also identified a phonological factor of segmentation that predicted the later reading and spelling skill of pre-readers.

The similar pattern for explanation of variance in both reading and spelling found, in this experiment for phonological production/segmentation and phonological memory, supports an argument of Hulme and Roodenrys (1995). They proposed that short-term memory problems are an indirect measure of the underlying phonological problems that cause reading difficulties. They suggested that the short-term memory problems of dyslexic children add to their problems with literacy but do not cause them. An association between children's short-term memory span and reading skill found by McDougall, Hulme, Ellis and Monk (1994) was explained by differences in speech rate. They expressed the view that the weak memory span of poor readers resulted from their slow speech rate and consequent poor processing of information in the articulatory loop.

The four third year factors, described in chapter 5, were identified from the test results of a reduced number of participants, who were selected by their results on earlier tests. The following limitations might also have affected the factors of phonological perception and phonological production. The stimuli chosen for phoneme discrimination and nonword repetition were both short lists of relatively simple nonwords (see Rack, Snowling and Olsen, 1992 for a review and discussion of the necessity of complex nonwords). Consequently chapter 6 described a new experiment that investigated, in unselected undergraduates, two specific tasks of phonological processing (nonword rhyme decision and Benton phoneme discrimination). These new tasks used longer lists of complex nonwords for stimuli. Rhyme decision is frequently used in the literature as a measure of phonological awareness (e.g. Bradley and Bryant, 1983) so this task was expected to tap differences in phonological awareness.

Surprisingly a statistically significant interaction was found between the two different types of phonological processing (nonword rhyme decision and Benton phoneme discrimination) and hand skill. As predicted, by the RS Theory, those with difficulties with nonword rhyme decision were found to be less dextral than those without, occupying the position, on the handedness continuum, expected for a group including a majority with no bias to dextrality. In contrast and against predictions, those with difficulties with phoneme discrimination were found to be *more dextral* than those without, occupying the position expected for a group that included a majority with a constant bias to dextrality. Unexpectedly deficits in different phonological processing abilities were demonstrated at different parts of the handedness continuum. Different deficits were expected to be found in each half of the continuum but they were not anticipated to be different *phonological* deficits.

A non-significant linear trend for Annett hand preference sub-group was also found for specific rhyme decision and phonological discrimination deficits. Those with the two different types of specific deficit were found in the positions expected for groups with either no bias or a strong bias to dextrality. Those with specific difficulties in phoneme discrimination were only found in the four right handed sub-groups plus the one left handed sub-group (group 6) which is most shifted to dextrality (as would be expected for any group with a strong bias to dextrality). However those with specific rhyme decision difficulties were found in all of the Annett hand preference sub-groups (as would be expected for a group with no bias to dextrality).

Evidence supporting a genetic influence on both of these aspects of phonological processing was also demonstrated when the handedness of relatives of those with the two different specific phonological deficits was examined. Statistically significant differences were found for maternal, paternal and sibling handedness (highly significant) although the chi-square assumption for cells with expected frequencies of less than five was violated in some analyses. Those with specific nonword rhyme difficulties included the highest percentage of left handed fathers (but not mothers), the majority of those with two left handed siblings and a minority of those with no left handed siblings. Conversely those with specific phoneme discrimination deficits included the lowest percentage of left-handed mothers and fathers and a minority of those with any left handed siblings.

The low number of left-handed mothers of those with nonword rhyme difficulties is puzzling but it could be affected by social influences having a stronger effect upon females than on males. Strong social influences could cause fewer females than males who lack the typical bias to dextrality (and are at risk for deficits in phonological processing) to be left-handed. Consequently more mothers than fathers who lack the rs+ gene would be right handed due to social pressures. These right handed, rs—genotype, mothers however would be unable to pass the gene on to the next generation who would then be at risk of phonological difficulties if they did not receive a copy of the gene from their father. However this does not explain why the group with neither problem (phonological discrimination or rhyme decision/phonological awareness) had most left handed mothers. It is possible that this group includes many individuals with no bias to dextrality who have neither phonological problem because their speech processing is lateralized by chance in the most beneficial arrangement. This could be interpreted as providing support for a prediction of the RS Theory for the existence of such a group who are expected to have superior abilities, as they suffer neither the slight insult to the right hemisphere that accompanies possession of the rs+ gene nor the risk to phonological processing which goes with its absence. This group would be expected to be found more frequently in an undergraduate population as in this sample.

An alternative explanation could be that the expression of left-handedness is affected by a modifier gene that is carried on the X chromosome and results in a higher prevalence of left-handedness in males than females (as proposed by McManus and Bryden, 1992). This modifier gene works by inactivating D (for dextral) alleles, temporarily preventing them from causing directional asymmetry, and so resulting in fluctuating asymmetry. McManus and Bryden predict a maternal effect for the modifier gene so that female left-handers are more likely to transmit the C allele (for chance or random handedness) to their offspring than male left-handers. However, the social influence explanation appears simpler and more effective, having the advantage of not requiring the addition to the model of extra parameters.

Besides predicting a risk to phonological processing that is present in those who lack the typical bias to dextrality, the RS Theory also predicts a risk to another ability for those with a strong bias to dextrality. Different specific deficits are expected to be at risk for both homozygotes (rs-- and rs++) although the particular types of phonological processing or other ability that are at risk have not been specified as yet. Phonological processing was only expected to be at risk in those who lack the bias to dextrality but the new findings in this thesis suggest the possibility that different types of phonological processing could be at risk when the bias to dextrality is either absent (rs--) or strong (rs++).The risk to the rs-- genotype would be for difficulties in phonological awareness or rhyme awareness and the risk for the rs++ genotype would be for phonological discrimination (or perception). This would leave those with a mild bias to dextrality (heterozygotes rs+-) with no risk to either type of phonological processing. This new proposal does not conflict with predictions of the RS Theory as the proposed deficit in phonological perception in those with a strong bias to dextrality could be part of a multi-sensory perceptual deficit as proposed by Stein and Walsh (1997). Annett has suggested that the ability that is at risk for the rs++ genotype could be one of visual processing and Stein's multi-sensory magnocellular deficit hypothesis would include visual difficulties. Discussion of this proposal will be returned to later.

An alternative hypothesis is that phonological awareness could be at risk in those who lack the rs+ gene while *all* those who possess a copy of the gene could suffer a deficit in phonological discrimination. This would lead to mild difficulties in the rs+- genotype and stronger deficits in the rs++ genotype. The mild perceptual difficulties in the rs+- genotype would be a minor cost to the majority for the benefit of normal development of a speech processing system in the left cerebral hemisphere. This would still ensure, in normal development, a generally good level of phonological skills. Some tentative support for this proposal appears when the percentage of undergraduates making more than three Benton phoneme discrimination errors (36%) is compared with the genotype frequency of the rs++ genotype (0.3242). The additive model of the RS Theory predicts that the disadvantage to the right hemisphere that is incurred by possession of one copy of the rs+ gene is doubled when two copies are present (as in the rs++ genotype). This has been supported by findings of Annett and Kilshaw (1983) that strong right-hand preferences, especially in females, are associated with weak left hand skills. However this would not alter the premise that a multi-sensory magnocellular deficit could cause the difficulties with phonological perception found in those with the typical shift to dextrality.

The final experiment, reported in chapter seven in this thesis, involved a sample that was selected to increase the representation of left and mixed handed subjects. Previous studies using dichotic listening, to assess cerebral lateralization in normal subjects, have often excluded non-right handers because such investigations usually exclude subjects who are likely to be atypical. However as atypical cerebral lateralization was of interest here the sample was chosen to include approximately equal proportions of pure left, mixed and pure right-handers. All subjects in this sample had their hearing tested before completing the other tasks and any with discrepancies of more than 10 decibels between their ears were excluded from analyses concerning dichotic listening. A first factor analysis of test data from this whole sample identified three factors of phonological production (or segmentation), dichotic listening and phonological awareness (or rhyme awareness). Muter, Hulme, Snowling and Taylor (1997) also identified separate phonological factors of segmentation and rhyme (from a battery of tests given to children before they learned to read). In this thesis an association, in the expected direction, was demonstrated between phonological processing and handedness with poor phonological production/segmentation being associated with reduced dextrality. This again supported proposals of the RS Theory for a risk to phonological processing in groups with reduced dextrality.

A new factor analysis included data from further phonological tasks, (of nonword repetition, digit span, and phonological discrimination) that were not available in the first year of testing, and this resulted in the identification of five factors. These represented phonological production/segmentation, dichotic listening, phonological memory, phonological awareness (or rhyme awareness) and phonological perception. Groups of subjects with LEA, REA or equal ear advantage on a task of dichotic listening were found to differ for both phonological awareness (highly significant) and phonological perception (a non-significant trend and significant contrast between LEA and REA).

One atypical pattern (no strong lateralization to either ear) was found to be associated with poor phonological awareness. This supports an expectation of the RS Theory that a group with the atypical pattern of no strong lateralization to either ear is at risk for phonological deficits. In this group, different aspects of phonological processing could be lateralized at random in the two cerebral hemispheres. This could result in phonological problems due to extra crossings of the corpus callosum that would be necessary *during* speech processing. Normal speech processing must involve at least one crossing of the corpus callosum when inputs from the two ears are combined. However additional crossings during processing would be expected to lead to delays in processing and an accompanying deterioration in signal quality. These findings are supported by the work of Pugh et al. (1997) who found evidence that differences in phonological ability were associated with differences in the distributions of RH-LH activation patterns.

Another atypical pattern (LEA) for dichotic listening was associated with both superior phonological awareness and phonological perception. This could be interpreted as providing support for a prediction of the RS Theory that there exists a group with atypical cerebral lateralization and superior abilities. This group with LEA could include many individuals with no disadvantage to the right hemisphere (as they had no factor inducing left hemisphere speech) together with no phonological disadvantage as their speech processes were lateralized together by chance. In this way they would have no phonological problems plus superior right hemisphere abilities as they lack the slight disadvantage to the right hemisphere caused by the typical factor for shift to the right hemisphere. Undergraduate samples, as in this experiment, are likely to include a larger proportion of individuals in this fortunate position than those of the general population.

Evidence for poor phonological discrimination was found in the group with the typical pattern of LH lateralization for speech processing in contrast to those with the atypical patterns of no lateralization (who were intermediate) or RH lateralization (who were superior). This supported the evidence of the previous experiment that the factor that induces the advantage of LH lateralization for speech (the rs+ gene) could also cause a risk to phonological perception, as all individuals who possess the rs+ gene would be expected to be included in the group with the typical pattern of LH speech processing. However it is not clear if all who possess a copy of the rs+ gene would be at risk of phonological perception deficits or if the risk is only for those whose speech lateralization to the LH is too strong (i.e. when two copies of the rs+ gene are inherited).

Poor phonological awareness was associated with the atypical pattern of no bias to either ear in dichotic listening and poor phonological discrimination (or perception) was associated with the typical pattern of right ear advantage. This supported suggestions made here that these are strong candidates for the deficits that are proposed by the RS Theory to be at risk in individuals who differ for the agent that influences the typical bias to the LH for speech processing (i.e. the rs+ gene).

The final analysis demonstrated further evidence of an association between handedness and specific types of phonological processing. Poor phonological production (or segmentation) was associated with reduced dextrality (highly statistically significant) and poor phonological perception was again associated with increased dextrality (statistically significant although assumptions for chi square of no expected frequencies of less than five were violated). The latter result was particularly impressive for two reasons. Firstly the association was still found in a sample that was selected to include increased proportions of left and mixed handers (and so reduced proportions of pure right handers). Secondly, both specific deficits were found in an undergraduate population that is, by definition, selected for ability. This could be interpreted as indicating that all individuals with a copy of the rs+ gene suffer mild phonological perceptual deficits.

These findings have led to the proposals that phonological production/segmentation (or phonological awareness) and phonological discrimination (or perception) could be the processes that are predicted by the RS Theory to be at risk at different ends of the handedness continuum. If so then poor phonological production/segmentation or poor phonological awareness would be the deficit associated with reduced dextrality (and absence of the rs+ gene) and poor phonological perception would be associated with increased dextrality (and presence of at least one copy of the rs+ gene). The possibility that the latter could be part of a multi-sensory problem, as proposed by Stein, has been proposed earlier and will be discussed later.

The evidence that phonological awareness is at risk in those of the rs-- genotype is strong but the evidence that poor phonological production/ segmentation could also be at risk in this group is not so powerful. Phonological production (or segmentation) was not statistically associated with ear advantage although trends were in the expected direction. Significant associations were however found with handedness so that poor phonological production (or segmentation) was associated with reduced dextrality. It is possible that the reduction in numbers in the final factor analysis (examining ear advantage) was sufficient to mask an effect for ear advantage. Alternatively the association between handedness and phonological production (or segmentation) could merely reflect the influence of phonological awareness on the tasks used to measure phonological production/segmentation. Several studies (e.g. Wagner & Torgesen, 1987, and Muter, Hulme, Snowling & Taylor, 1997) have identified two highly related factors of phonological awareness (rhyme) and segmentation that are necessary for the development of literacy skills. Further investigation, with larger samples, is necessary to clarify whether poor phonological production (or segmentation) is associated with a lack of bias to ear advantage for dichotic listening.

Research reported in this thesis has operated within the confines of a situation in which carte blanche was not available for the planning of experiments, as they had to fit in with existing research projects. Nevertheless within these confines a considerable amount of choice was still possible. A further restriction to the present work is the absence, at present, of a marker for the rs+ gene. However with the mapping of the human genome this situation is likely to change before too long.

All findings in this study relating to phonological awareness and phonological production (or segmentation) have been consistent, in the direction predicted by the RS Theory and either statistically significant or non-significant trends. Those for phonological discrimination have all been statistically significant and consistent but not in the expected direction. This accumulated evidence led to the proposals that phonological production could be the specific phonological process for which the rs-- genotype is expected to be at risk and minor difficulties with phoneme perception could be the disadvantage for the rs++ genotype (or the cost of possessing at least one copy of the rs+ gene). It has been proposed here that the difficulties with phonological perception found here could possibly be part of a multi-sensory problem as proposed by Stein and Walsh (1997). Stein suggested that the impairments of processing experienced by dyslexics result from abnormalities of the magnocellular system, which is specialized for processing fast temporal information. This hypothesis explains dyslexia without identifying phonological, visual or motor deficits alone but instead suggests that temporal processing in all three systems is likely to be impaired so that dyslexics may be unable to process fast incoming sensory information adequately in any modality. Talcott, Hansen, Assoku, & Stein (2000) have proposed that difficulties could be caused by dyslexics' motion detectors having a lower signal to noise ratio.

Multi-sensory difficulties in the magnocellular system, as proposed by Stein, would be expected to involve minor deficits in perception that would affect all modalities. Minor difficulties of this type may be found to explain some of the frequently listed symptoms of dyslexics (e.g. letters which swim around, clumsiness etc.). They may also account for the small deficits in phonological perception found in this study in participants with strong dextrality.

After decades of research, one of the major causes of dyslexia has been identified as a disruption in phonological processing. The importance of phonological skills for reading and spelling is now widely recognised but it remains unclear which factors underlie this processing problem and whether other, equally important deficits impair a person's ability to read. Considerable debate revolves around the question of whether dyslexics have, in addition to phonological problems, a general deficit in speed processing. Information that requires rapid rates of processing appears to be dealt with more slowly than normal, and it has been suggested that this speed deficit interferes with their ability to analyse letter patterns and text rapidly enough to become efficient readers. Several studies (e.g. Stein and Walsh, 1997; McAnally and Stein, 1997; McAnally, Castles and Stuart, 2000) have provided evidence to support the argument that this may be true for at least some dyslexics but others are dubious that a general speed-processing problem could be a major cause of the difficulties experienced by dyslexics. Instead, specific language-related causes, particularly within the phonological processing systems, are generally expected to be the problem. Much current research on dyslexia has focused on phonological awareness (e.g. Snowling, Bryant) and although it is extremely powerful as a line of research, a means of diagnosis and a method of remediation it cannot be denied that testing for phonological awareness alone does not identify all individuals with a reading disability. Neither does instruction in phoneme awareness improve the performance of all dyslexics (e.g. Bryne et al., 1995). Several studies have found that some dyslexics have deficits in phonological perception (e.g. Godfrey et al., 1981; Reed, 1989; Werker & Tees, 1987; Lieberman, Meskill, Chatillon & Schupack, 1985; Steffens, Eilers, Gross-Glenn & Jallad, 1992; Watson & Miller, 1993) and others have demonstrated difficulties with phonological production (e.g. Brady, Poggie & Merlo, 1986; Kamhi & Catts, 1986; Kamhi, Catts & Mauer, 1990).

The concept of a general speed-processing deficit in dyslexia resulted from Tallal's (1975) findings that children with language-learning disabilities (which may lead to dyslexia) process sounds more slowly than normal, and that this diminishes their ability to distinguish phonemes. Evidence to support this theory comes from studies that measure how much time children need between two sounds before recognizing that there is more than one sound. This "timing threshold" includes the time it takes nerve cells to fire, to process a sound's acoustic features and then to recover enough to pick up the next sound. Normally a child has an average "timing threshold" for simple tones that falls within a range of tens of milliseconds. However, children with language-learning problems have "timing thresholds" measuring hundreds of milliseconds. The differences between many phonemes (e.g. "ba" and "da") occur within tens of milliseconds so children who need longer to detect changes may not hear a distinction. Unable to hear a difference between certain phonemes, these individuals may develop problems with mapping phonemes to words. Tallal and her colleagues have suggested that 85% of children with language-learning problems go on to develop dyslexia.

It has been argued that dyslexics do not demonstrate deficits in other tasks requiring rapid processing (e.g. music and athletics) but reading and language processing are likely to be the most difficult and rapidly paced tasks that most individuals normally try to accomplish. Fast temporal processing may be necessary for music and athletics but it would not be equivalent to the speed that is involved in processing words when reading and comprehending a sentence. In addition not everyone is expected to be a skilled athlete and musician, but we do expect everyone to become an accomplished reader.

The role of magnocellular cells in dyslexia was first suggested by Livingstone et al., in 1991, when it was proposed that reading involves light striking the photoreceptors in the retina, so that information is processed in the midbrain by the magno and parvo cells. After passing through these two types of cells the information proceeds to the visual cortex for further processing. It has been suggested that this major pathway is slow in dyslexics so the two types of visual information are presented in an incorrect sequence (Newman, 1998). Livingstone, Rosen, Drislane and Galaburda (1991) demonstrated that cells of the magnocellular (but not the parvocellular) layer of the lateral geniculate nucleus were significantly smaller in five dyslexics than in five controls. The "formally diagnosed" dyslexics showed a pattern of response that would be expected if there were an impairment of the magnocellular division of the visual system.

So far much of the evidence in favour of the magnocellular theory has involved visual difficulties (e.g Livingstone, Rosen, Drislane and Galaburda, 1991; Talcott, Hansen, Assoku and Stein, 2000) but some studies have shown deficits in auditory processes (e.g. McAnally and Stein, 1997). Menell, McAnally and Stein (1999) have shown that dyslexics had a reduced sensitivity to amplitude modulation (AM) of acoustic stimuli in comparison to controls. They proposed that this deficit in AM sensitivity could result in impaired perception of the AM present in speech. Many individual phonemes are very similar and an impaired perception of the AM in speech is likely to be sufficient to cause the minor phoneme discrimination difficulties, which have been found in this study in those with strong dextrality.

As yet sensory processing has rarely been examined across visual and auditory modalities within the same individuals. However one study by Witton et al.(1998) found a high correlation between thresholds to both visual coherent motion and frequency modulation (i.e. motion across the sensory epithelium of the cochlea) in the same individuals. Future studies that establish the hand preference of individuals displaying high thresholds to both would be expected to find them in the Annett hand preference sub-groups that include most individuals who are shifted to the right in handedness.

The role of a magnocellular deficit in dyslexia has been the subject of much dispute (Stein, 1991; Lovegrove, Martin & Slaghuis, 1986; Lovegrove, 1991) but there does seem to be a reasonable argument in favour of an impaired magnocellular system having at least some influence (Breitmeyer, 1993a). Several studies have shown that at least *some* dyslexics appear to have defects in their main magnocellular pathways (e.g. Demb, Boynton, and Heeger, 1998; Demb, Boynton, Best and Heeger, 1998). Some studies, but not all, have found evidence in favour of the theory (Menell, McAnally and Stein, 1999; McAnally and Stein, 1997), but sampling bias could explain the variation if only some dyslexics are expected to have a magnocellular deficit. The existing data on the magnocellular deficit theory is still conflicting and it has been suggested by some researchers (e.g. Borsting, 1996; Skottun, 1997) that magnocellular deficits may be linked to only one sub-type of dyslexia.

There has also been little research examining the relationship between patterns of dyslexia and sensory processing deficits. Some studies have tentatively supported a hypothesis that sensory deficits may be more prevalent in phonological dyslexia than in surface dyslexia. Borsting and colleagues have used Boder's classifications (Borsting et al., 1996 and Ridder et al. 1997) to demonstrate that magnocellular pathway deficits do not occur in dyseidetic dyslexics (with lexical-type reading impairments) but are found in severe dysphonetics (with nonlexical-type impairments) and dysphoneidetics (with a mixed pattern of deficits). Spinelli et al. (1997) also found no evidence for visual magnocellular deficits in Italian surface dyslexics but as Italian is a transparent language such deficits are likely to be difficult to demonstrate. McAnally, Castles and Stewart (2000) have proposed several possible relationships between sensory deficits and different patterns of reading difficulty. They have suggested that visual and auditory deficits could co-occur in individuals who display phonological and mixed dyslexic profiles but not in those who show surface dyslexic patterns. Alternatively they propose that the deficits could co-occur in all dyslexics or they could occur in isolation in particular sub-groups of dyslexics suggesting that they have different effects across modalities on component processes in reading. The findings in this thesis raise the possibility that co-occurring visual and auditory deficits could be expected to exist in surface type dyslexics while auditory deficits alone could be found in phonological dyslexics. However at present much more work is needed to test effectively the relationship between multi-sensory deficits and different patterns of reading difficulty.

The evidence presented in this thesis could reconcile the divergence between the two fields of research into phonological deficits and into magnocellular deficits. If some individuals, with a reduced shift to dextrality, have a deficit in phonological awareness and others, with an increased shift to dextrality, have a deficit in phonological perception then both theories could be valid but in any individual case the application of only one theory would be appropriate. A theory of phonological deficits would explain the difficulties experienced by those with problems with phonological production/segmentation or awareness (and a reduced shift to dextrality) while the magnocellular theory could explain the difficulties experienced by those with phonological perception deficits (and an increased shift to dextrality).

Learning not only what causes dyslexia, but also the source of experimental discrepancies, is necessary before we can understand the conflicting results and conduct research to help in the battle against these learning disabilities. It is proposed here that the differing phonological deficits found in those with both reduced and increased dextrality could help explain some of the confusion that has long affected the literature concerning specific reading and spelling difficulties and also appears to be affecting the literature on magnocellular theory. Sampling bias in different experiments would be expected to produce diverse results, as some studies could include a majority of dyslexics with one type of phonological problem while others could include a majority with the other phonological difficulty. As these phonological abilities are expected (and have been found) to vary in normal populations the abilities of controls could also vary from study to study depending upon the type of assessment procedure used when identifying dyslexics and controls.

This thesis has used a dual route model of reading as a tool and a multi-sensory magnocellular deficit could cause problems with the lexical route, in this type of model, while a specific difficulty with phonological awareness could adversely affect the non-lexical route. These differing deficits could explain the two groups of dyslexics that have been identified at different ends of the continuum of handedness (Annett & Kilshaw, 1984; Annett, Eglinton and Smythe, 1996), the two types of poor spellers similarly identified in this thesis and the poor readers found at both ends of the hand skill distribution (Annett & Manning, 1990). Those who are strongly shifted to dextrality would be expected to be at risk for multi-sensory magnocellular deficits and to have difficulties with the lexical route for reading. In contrast, those with reduced dextrality would be expected be at risk for difficulties with phonological production or phonological awareness which would cause problems with the non-lexical route.

Current connectionist models have demonstrated many aspects of phonological and surface forms of developmental dyslexia (Harm & Seidenberg, 1999). Connectionist networks consist of a large number of simple neuron-like units with pools of units that correspond to various features. In this way one set of units would correspond to the 'b' in 'bat' while a different but similar set would correspond to the similar sound of 'p' in 'pat'. Mappings from orthography to phonology happen via an inter-level of hidden units and different weightings (according to how often words are seen) allow for varying sensitivities to frequency effects etc.

Seidenberg has proposed that access to meaning can be achieved directly in one step from orthography to semantics or indirectly in two steps from orthography through phonology to semantics. Feedback from the hidden units allows correlations to be picked up and activation of a semantic code is based on continuous pooled input from the two sources. In this model few words need both pathways and activation is taken from whatever source is first available. Unlike the dual route theory most words are read on a co-operative basis so that multiple interacting sources are involved. It is suggested that the phonological pathway develops first and the orthography to semantics pathway takes time to develop but skilled reading needs both parts plus their interaction. Impairments in phonological output were found to have the largest impact on the processing of unfamiliar material (e.g. nonwords) and it was suggested that magnocellular deficits could affect the processing of single words by degrading the input to the model. This supports suggestions made in this thesis that deficits in phonological awareness could be responsible for the difficulties of one type of dyslexic (phonological) while deficits in a general multi-sensory magnocellular deficit (that includes phonological perception) could cause the problems of another (surface type).

Both major models of reading would be affected by the deficits that have been suggested in this thesis and they can both explain the difficulties with reading that would result from these deficits. In addition these difficulties with reading have frequently been found in two different types of developmental dyslexia and they have been identified in two groups displaying strong dextrality or reduced dextrality, as is predicted by the Annett RS Theory. Annett (1985) hypothesized that the main role of the rs+ gene could be 'to facilitate the development of a speech output-input system on the left side of the brain'. The research presented here has found evidence of difficulties in specific aspects of phonological processing affecting speech "input" and "output" that are associated with differences in cerebral laterality, handedness and familial handedness. Unfortunately it is not yet clear whether the deficit in phonological processing for which those in the rs—genotype are at risk is one of phonological production or phonological awareness. However future research can be aimed at distinguishing the contribution of these two components of phonological processing. Hulme and Roodenrys (1995) have suggested that a slow speech rate causes poor processing of information in the articulatory loop which contributes to the poor short term memory of dyslexics. A slow speech rate is also likely to affect the development of phonological awareness so the similar effects found in the present work for phonological production and phonological awareness could be due to this influence.

The implications of this research for teaching practice are considerable. Recognition that different phonological difficulties could contribute to two differing types of dyslexia and that one of these difficulties could be part of a multi-sensory magnocellular deficit could lead to the planning of different strategies for the two types of dyslexic. It is expected that compensating abilities will be employed as literacy develops and some children will be better able to compensate than others. Early programmes of practice in phoneme awareness would be expected to help many children but others might benefit from practice in multi-sensory awareness. Programmes of preschool phoneme awareness training have been found to improve the reading of many, but not all, children (Byrne & Fielding-Barnsley, 1995; Byrne, Fielding-Barnsley, & Ashley, in press 2000). Interestingly Byrne et al. found that future success in reading was best predicted by children's speed in responding to early instruction not how well they responded. If speed processing is the difficulty involved in the magnocellular deficit then the children who are slow to respond could be those who would benefit from multi-sensory training.

Another implication of this research is the possibility that deficits in phoneme discrimination could be used as a marker for the rs+ gene. If *all* individuals with at least one copy of the rs+ gene are expected to suffer difficulties with phoneme perception, and multi-sensory magnocellular deficits, then evidence of the presence of these deficits (in a mild or stronger form) could identify them (and hence the rs+ gene). Alternatively all individuals with one copy of the gene may only experience extremely minor phonological discrimination difficulties while those with two copies are more severely affected. If this is true then phonological discrimination deficits could be used as a marker for identifying most individuals in the rs++ genotype. However independent confirmation of these findings will be necessary before this implication could be pursued further.

Other avenues of research are also suggested by the present findings. Exploration of the relationships between genes for dyslexia (Cardon, Smith, Fulker, Kimberling, Pennington and Defries, 1994; Pennington, 1990; Fisher, Stein, Monaco, 1999) and the various genotypes of the rs locus would be expected to yield profitable results. Complex relationships are also expected to exist between types of dyslexia and patterns of cerebral processing but further brain imaging studies should eventually help to clarify the situation if the handedness of participants is carefully established (as in Paulesco, Frith, Snowling, Gallagher, Morton, Frackowiak, and Frith, 1996).

This thesis began by presenting evidence, consistent with the literature and with predictions of the RS Theory that difficulties with phonological processing are to be found in individuals who, as a group, are less dextral than the majority. It was demonstrated that this effect for handedness was present in the population as a whole and was not just the effect of a disabled minority. Poor spellers and poor readers with phonological difficulties were both found to be considerably less dextral than controls and those with literacy difficulties, which did not involve phonological processing. Evidence from further experimental work with children and undergraduates led to two new hypotheses. It was suggested that not only could phonological production/segmentation or phonological awareness be the specific phonological deficit that is at risk in those with reduced dextrality, but also that phonological perception could be a specific deficit, found in those individuals with increased dextrality. These deficits were found in the general population, and in groups of undergraduates who are selected for general ability, so again the effect could not just be due to poor general ability. Support was also demonstrated for the proposals of a genetic influence (the presence or absence of the rs+ gene) on these different aspects of phonological processing. Groups of individuals with these specific deficits were found to vary in the number of left handed relatives that they possessed.

A final implication of this research is that it is an indication of the wide range of diversity (of deficits and talents) in the general population that can result from small genetic influences on normal development combined with the ever-present influence of chance. We are only slowly becoming aware of these variations and at a time when the mapping of the whole human genome has been recently completed this is an important factor to be borne in mind by all who work in areas which will be affected by these new discoveries. Care must be taken that diversity is respected and preserved.

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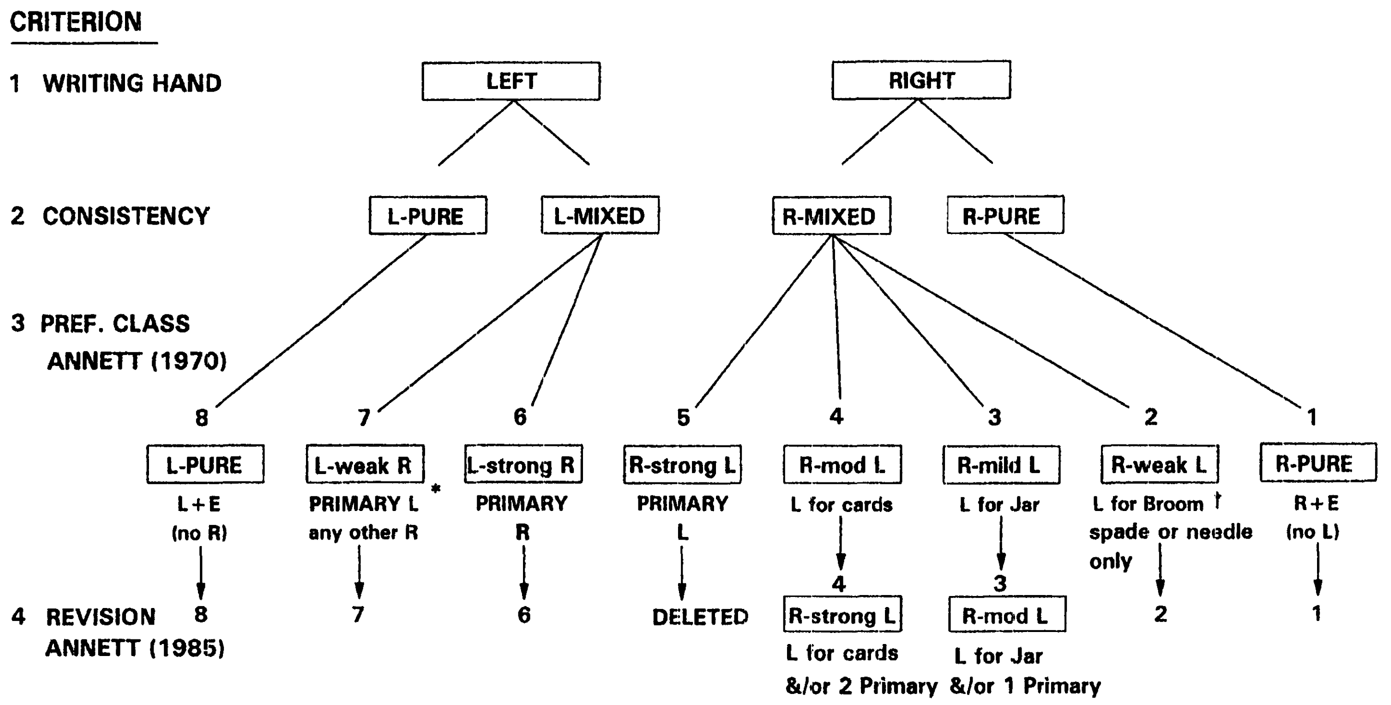
Appendix A

The Annett decision tree for hand preference (revised 1985)

A DECISION TREE FOR HAND PREFERENCE



* PRIMARY ACTIONS are Writing, Throwing, Racket, Match, Hammer, Toothbrush
NON PRIMARY are Scissors, Needle, Broom, Spade, Dealing cards, Unscrewing jar
† Classes to the left take precedence

Appendix B

Word order task wordlist (task 1.2)

NAME: BOY/GIRL SCHOOL:

SUN	GUN	FUN	NUN
CAP	LOT	DEN	TUN
FEED	DEED	WEED	SEED
END	SOW	MAN	TILL
ROD	ROCK	ROLL	ROT
FIN	TAP	PEG	HUG
DOT	LOT	COT	POT
MOP	TOY	BET	FIG
PIG	PIN	PIT	PIP
JAM	BELL	DOG	FAT
HAS	HAD	HAT	HAM
FOX	MAP	RED	BUS
MISS	MCSS	MAN	MEN
KICK	PEEL	DROP	BUN
OAT	EAT	IT	AT
HILL	BOOK	TREE	GRIN
BIN	BAN	BUN	BEN
NAIL	DASH	FILM	SEAT

Appendix C

Spelling test wordlist (task 1.4)

1. **Final** – as in soccer final
2. **Circus** – a travelling circus with tents and animals
3. **Increase** – an increase in the price of something
4. **Slippery** – a path is slippery with ice
5. **Lodge** – a lodge to stay in for the night
6. **Style** – the style of fashion for clothes
7. **Bargain** – a bargain to buy at the sales
8. **Copies** – several copies of a newspaper
9. **Guest** – a guest was visiting us
10. **Policy** – the government's policy to do something

Appendix D

Word discrimination test wordlist (task 1.3)

1.	ROOT	ROUTE
2.	SAW	SORE
3.	FLOWER	FLOUR
4.	TOW	TOE
5.	SEE	SEA
6.	RING	WRING
7.	FUR	FIR
8.	BOY	BUOY
9.	BAWL	BALL
10.	BEECH	BEACH
11.	FEET	FEAT
12.	FLOOR	FLAW
13.	HEEL	HEAL
14.	OR	OAR
15.	PAWS	PAUSE
16.	BRED	BREAD
17.	WITCH	WHICH
18.	TEE	TEA
19.	WOOD	WOULD
20.	SUN	SON
21.	WAY	WEIGH
22.	NOT	KNOT
23.	KEY	QUAY
24.	MEET	MEAT

Appendix E

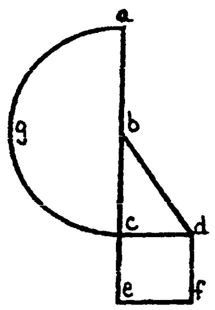
Nonword spelling list (task 1.5)

1. **Gouse (douse)**
2. **Doney (money)**
3. **Charch (march)**
4. **Fape (cape)**
5. **Toble (table)**
6. **Nater (later)**

Appendix F

Shapes and marking instructions for NFER visuo-spatial task (1.6)

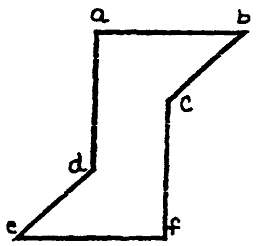
Complete Set of Marking Points



JSA09

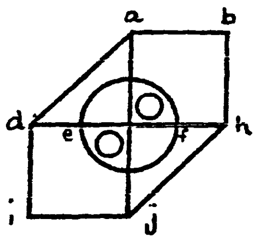
1. agcd intersects ae at c [where c is the top corner of the square]
2. bcd is a right angle
3. ce = ef
4. cd is common to Δbcd and □cdef

5* ac = 2bc (b must be on ac)
6* bc = 1.5cd (bcd is the Δ)



JA07

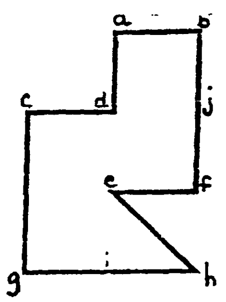
1. The overall shape is 6 sided.
2. a and f are right angles.
3. ab || ef
4. ab = ef
5. ed = cb



JSA 13

1. dij is a right angle
2. aj = 2ij
3. dh = 2 (the diameter of the circle at points e and g
4. ad and hj are joined and ||

5* abh is a right angle
6* dh = 2bh



JSA11

1. cd = ab
2. ef = fh
3. bf = cg and bf || cg
4. ef || ab

5* ai = 1.5gh
6* cj = 2ef, where j is the continuation of cd

* These items could be omitted if five or six points are too time consuming to mark.

Appendix G

Corpus of accepted nonword spellings (task 1.5)

Gouse	gouse gowes gause gouce gauws gous gaus gowse gows gouss gouss goase gowce gousce gauce ghous gouc goouse gowcs gouwse
Dunny	dunny donny dunney doney dunie dunnie dony donnie donee duney donney duny dunne dunea dune donee dunni donie duni duneay dunniy
Charch	charch chaarch chartch charche charcth chach chache
Fape	fape phape faip phap faipe fap faph fayp fhap faype
Toble	toble tobl tobol tobil towbal tobbal tooball touble tobale toebell toeboll tobll tobual
Nater	nater naiter natta natar nata nayter nator naitor natea nattar nature neighter naytah naita naghter neyter naeter natre nattur natuer

Appendix H

Wordlists and instructions for phoneme segmentation task (1.12)

Version 1.

"Do you mind if I switch the tape recorder on?" "(name ....)"

"I am going to say a word. I would like you to say the word back to me but with a sound missing - like this. If the word is jam and I ask you to say it without the 'j' you would say .....?"

jam (j) .... "(Yes) you would say am".

"Now try ball without the 'b'?"

ball (b) .... "(Yes) you would say all".

[Additional]

"part without the 'p'?"

part (p) ....

"face without the 'f'?"

face (f) ....

If still cannot do finish with thanks

"Now try these":-

"farm without the 'm'?" ....

"think without the 'k'?" ....

[Additional]

"pink without the 'k'?"

pink (k) ....

"paint without the 't'?"

paint (t) ....

If still cannot do go to * at end

"pint without the 't'?"......................

"find without the 'd'?"......................

"hero without the 'o'?"......................

"bind without the 'n'?"......................

"cold without the 'l'?"......................

"crow without the 'r'?"....................

*"ham without the 'h'?"........

*"hall without the 'h'?".........

"Thank you (name)" (and whatever seems appropriate). (Switch off recorder)

Version 2.

"I am going to say a word. I would like you to say the word back to me but with a sound missing - like this. If the word is fall and I ask you to say it without the 'f' you would say ....?"

fall (f) ....? "(Yes) you would say all".

"Now try near without the 'n'?"

near (n) ....? "(Yes) you would say ear".

[Additional]

"sand without the 's'?"

sand (s) ....

"many without the 'm'?"

many (m) ....

If still cannot do finish with thanks

"Now try these"

"fork without the 'k'?" ....

"card without the 'd'?" ....

[Additional]

"band without the 'd'?"

band (d) ....

"beat without the 't'?"

beat (t) ....

If still cannot do go on to * at the end

"wind (as in clock) without the 'd'?".............

"heart without the 't'?"................................

"china without the 'a'?"...............................

"rind without the 'n'?".................................

"child without the 'l'?"................................

"bread without the 'r'?"...............................

*"ham without the 'h'?"............

*"hall without the 'h'?".............

"Thank you, you have been very good". (or whatever seems appropriate).

Appendix I

Word list for reading test (1.11)

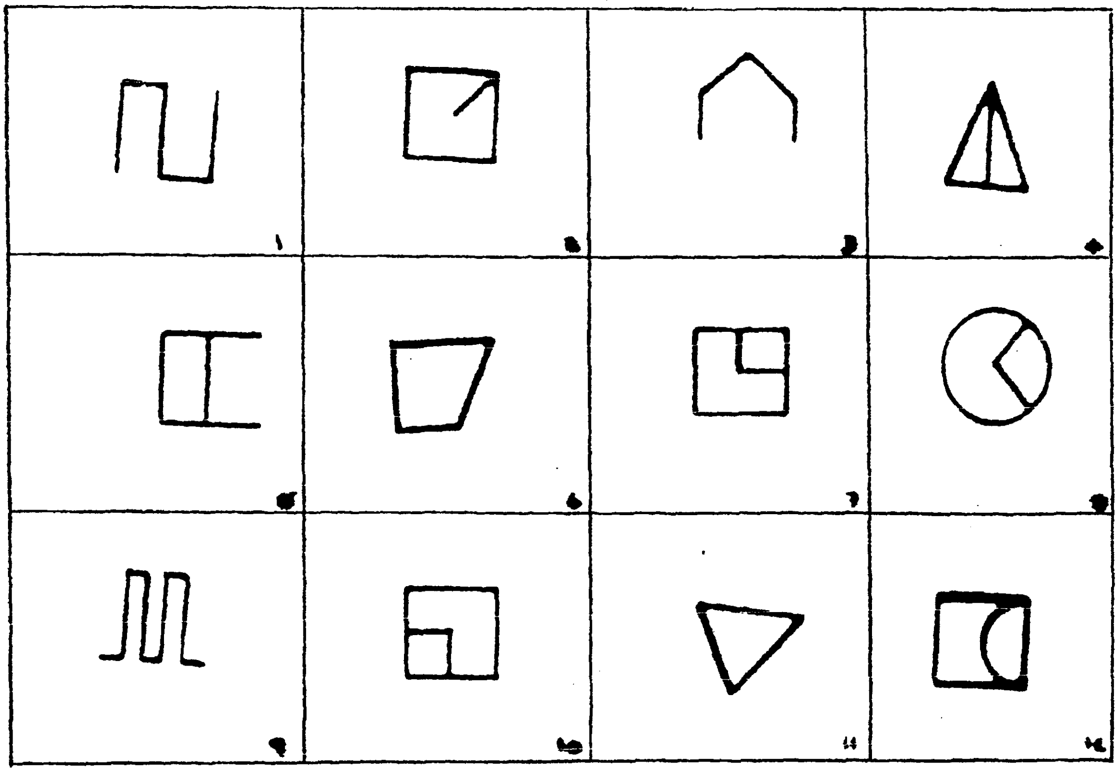
Here is a card with a lot of words. Let's see how many you can read. Read then out aloud to me.

on	he
you	fish
van	out
bird	running
clock	dig
money	light
oil	paper
knock	sport
glove	harvest
ladies	leather
chain	collect
favour	guest
massive	beard
statue	transparent
dough	obscure
diameter	environment
velocity	divulge
jeopardy	criterion

They are a bit harder now aren't they? Look at all the other words and if you know any of them tell me.

Appendix J

Shapes for visual task (1.13)



Appendix K

Annett (1970) hand preference questionnaire

UNIVERSITY OF LEICESTER
DEPARTMENT OF PSYCHOLOGY

DATA SHEET Hand Preference & Hand Skill

1. Annett (1970) Hand Preference Questionnaire

Name .... Age .... Sex ....

Were you one of a multiple birth (twins, triplets etc.) or were you single born?

Tick one: Twins etc. Single born

Please use the materials provided to demonstrate to your partner how you do the following actions?

E should record R (right), L (left), E (either)
Use 'either' only if S feels equally comfortable with either hand, and is sure there is no preference.

1. Write your name ____________
2. Throw a (paper) ball to E ____________
3. Bat the paper ball to E ____________
4. Hold a match while striking it ____________
5. Cut with scissors ____________
6. Guide a thread through the eye of a needle (or guide the needle onto the thread - the hand doing the guiding) ____________
7. Sweep with a broom - hand at top ____________
8. Shovel sand (mime) hand at top ____________
9. Deal playing cards ____________
10. Hammer a nail into wood ____________
11. Brush teeth with toothbrush (mime with brush) ____________
12. Unscrew the lid of a jar ____________

Appendix L

Auditory discrimination wordlist and instructions (task 1.17)

Minimal pair repetition I am going to say two words. They might be the same word or two different words. Will you tell me if they are the same or different?

bus - bus ____________ Yes, they are the same

bus - bud ____________ Fine (or if necessary) Bus and Bud are different"

" Now I am going to say two pretend words. I would like you to tell me if they are the same - or if they are different."

1 (food) poot toop__________

2 (hot) bon mon__________

3 (pit) wid wid__________

4 (hot) nop nop__________

5 (time) dibe nibe__________

6 (date) hape hape__________

7 (pit) vil vin__________

8 (bung) nung nung__________

9 (time) libe libe__________

10 (food) loof loof__________

11 (bun) lup lut__________

12 (date) daig gaid__________

Appendix M

Nonword repetition wordlists and instructions (task 1.18)

Nonword Repetition (PAPLA 8)
"I am going to say a pretend word and I would like you to say it after me"

A
1. ality ____________________
2. vater ____________________
3. splant ____________________
4. crealth ____________________
5. egular ____________________
6. drattle ____________________

B
7. riety ____________________
8. ipical ____________________
9. sprawn ____________________
10. ampty ____________________
11. drange ____________________
12. polid ____________________

Appendix N

Nonword reading lists (task 1.19)

ked	bem
nar	cug
fon	lat
shid	boak
doop	birl
dusp	soaf
snite	hance
hoach	smode
glope	grest
dringe	squate
churse	thease
shoave	pretch

Appendix O

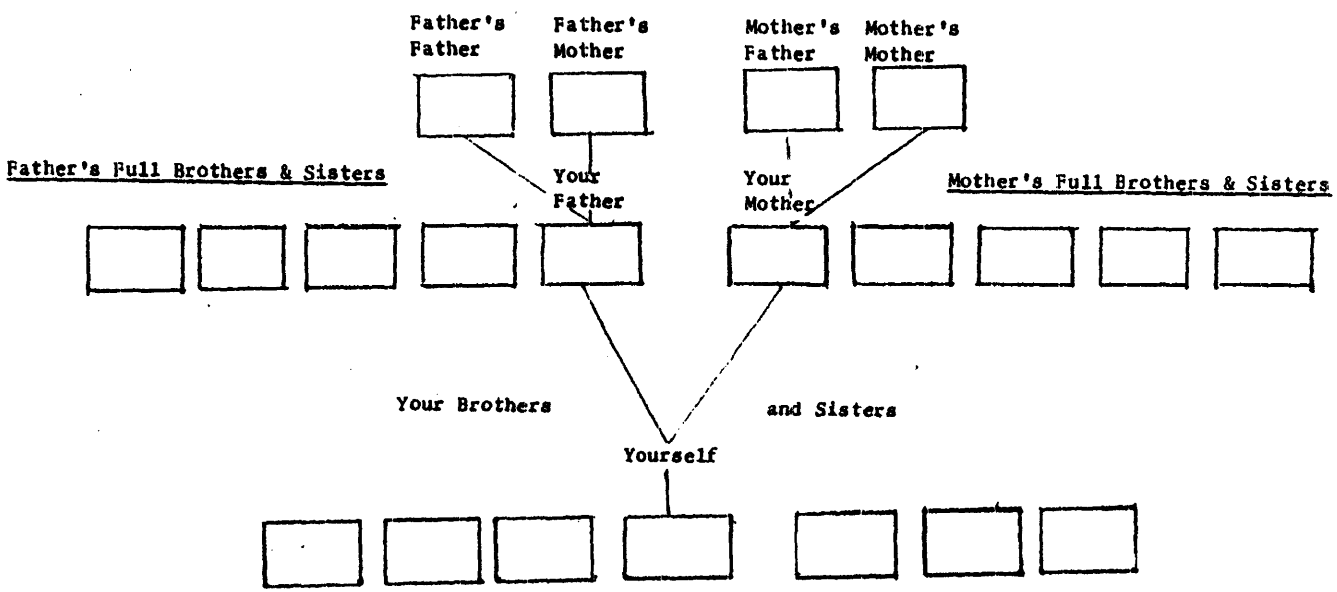
Annett family tree for handedness

FAMILY HANDEDNESS

This section asks you to give as much information as you can about the handedness of your own parents, grandparents, full brothers and sisters.

Please put the following symbols where appropriate in boxes below.

R for Right: L for Left: M for Mixed: O for Not Known



Please cross out surplus boxes ☒ or make more boxes where necessary.
Indicate sex of yourself and your siblings, uncles, aunts. ♂ Male ♀ Female.

Appendix P

Nonword list for pretend word rhyme decision task (2.5)

TROCT	DESH	________
STAWN	JORN	________
PLUNE	LEWN	________
PUTH	MOIM	________
PORL	VAWL	________
SHOLD	SKARN	________
GLINGE	RINJH	________
ERCH	SIFE	________
BRAM	SCHUME	________
TUDE	GEWD	________
BLOACH	CIVE	________
TRUDE	DUDE	________
THROLL	BLOTHE	________
BRONE	DOAN	________
DORL	JAWL	________
JOAL	WOLE	________
PLADGE	NUTCH	________
LEBE	TEEB	________
FLURE	BARL	________
TRAS	BLICE	________

Appendix Q

Nonword list for Benton phoneme discrimination test (2.4)

PHONEME DISCRIMINATION RECORD FORM*

Name ______________________________ No. ________ Date ____________

Age ____ Sex ____ Education ________ Handedness ______ Examiner ________

Item	Response	Item	Response
1. (D)bä-bō	______	16. (D)gētä-gätä	______
2. (D)sē-so͞o	______	17. (S)arak-arak	______
3. (S)tō-tō	______	18. (D)aksäd-aksān	______
4. (D)ur-är	______	19. (D)vemē-venē	______
5. (S)bä-bä	______	20. (S)kejē-kejē	______
6. (S)lo͞o-lo͞o	______	21. (S)pedzap-pedzap	______
7. (D)nō-tō	______	22. (D)kwēfäb-kwēfäd	______
8. (S)ur-ur	______	23. (D)ûrsit-ûrsat	______
9. (S)so͞o-so͞o	______	24. (S)slidig-slidig	______
10. (D)do͞o-lo͞o	______	25. (D)pedzap-pelzap	______
11. (S)vemē-vemē	______	26. (D)lamäd-lemäd	______
12. (S)aksän-aksän	______	27. (S)kwēfäd-kwēfäd	______
13. (D)kejē-kejō	______	28. (D)klidig-slidig	______
14. (S)gätä-gätä	______	29. (S)ûrsat-ûrsat	______
15. (D)ōrak-ôrak	______	30. (S)lamäd-lamäd	______

(The sound symbols are those of the pronunciation key of the Random House Dictionary of the English Language, New York, 1967)

No. correct Same responses ____
No. correct Different responses ____
Total correct ____

No. Same errors ____
No. Different errors ____
Total errors ____

Comments:

*A.L. Benton, K. Hamsher, N.R. Varney & O. Spreen. CONTRIBUTIONS TO NEUROPSYCHOLOGICAL ASSESSMENT.

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Appendix R

Instructions and wordlist for spoonerisms task (3.5)

Experimentors instructions:-

"I should like to use the tape recorder to record your responses so that I can score them later but if you prefer I can do this as we go along".

Name_"________________________" No. " ______________"

"I'm going to say pairs of words to you and what I want you to do is to exchange the first sound of each word, like this,

if I say	KEY CHAIN	I want you to say	CHEE KAIN
if I say	BONES and JOINTS	I want you to say	JONES and BOINTS
if I say	WIND MILL	I want you to say	MIND WILL

Here are some practice trials :-

DAVID BOWIE	________________________	(Bavid Dowie)
TALKING HEADS	________________________	(Halking Teds)
FATAL CHARM "	________________________	(Chatal Farm)

(further training if needed)

(after 2secs - H)

(after 5 secs - repeat)

1	GEORGE BENSON	____________	(Borge Jenson)
2	CHUCK BERRY	____________	(Buck Cherry)
3	BAD MANNERS	____________	(Mad Banners)
4	JOHN LENNON	____________	(Lon Jennon)
5	LED ZEPPELIN	____________	(Zed Leppelin)
6	NEIL DIAMOND	____________	(Deal Niamond)
7	JIMMY REED	____________	(Rimmy Jeed)
8	JOHNNY CASH	____________	(Conny Jash)
9	BOB MARLEY	____________	(Mob Barley)
10	MARVIN GAYE	____________	(Garvin May)
11	RAY CHARLES	____________	(Chay Rarles)
12	MARC BOLAN	____________	(Barc Molan)
13	JETHRO TULL	____________	(Tethro Jull)
14	PHIL COLLINS	____________	(Kill Phollins)
15	DELTA FIVE	____________	(Felta Dive)
16	BOB DYLAN	____________	(Dob Billon)
17	THIN LIZZIE	____________	(Lin Thizzie)
18	FOUR SEASONS	____________	(Saw Feasons)

Appendix S

Instructions and wordlist for auditory acronym task (3.6)

Experimenters instructions:- Name____________________No.___________

"I am going to say three words to you and I would like you to tell me the new word that is formed by combining the first SOUND of all three words (in sequence).

Here is an example. If I say BAD - EMU - TIN, you would say - BEAT

If I say FILL - ICE - TEA you would say - FIGHT

Now try these for practice:-

pen - owl - tyre ____________)

foul - ear - dip ____________) If wrong give feedback

Now try these:-

tub - eighty - lion ____________

fog - all - next ____________

pun - aunt - kill ____________

hold - ache - toes ____________

red - oat - ball ____________

fat - eat - lips ____________

dig - island - down ____________

wed - eat - loop ____________

duck - out - lump ____________

boy - art - cut ____________

big - eagle - date ____________

sick - easy - leg ____________

cat - own - ten ____________

ring - eel - danger ____________

house - are - cow ____________

germ - end - top ____________ Thank you that is all of them."

Appendix T

Wordlist for nonword repetition task (3.11)

Name...................... No.......

Nonword Repetition

1 twamket ....

2 shravelorsk ....

3 spikrolg ....

4 stranklaft ....

5 plutchrepst ....

6 kipthim ....

7 pilshen ....

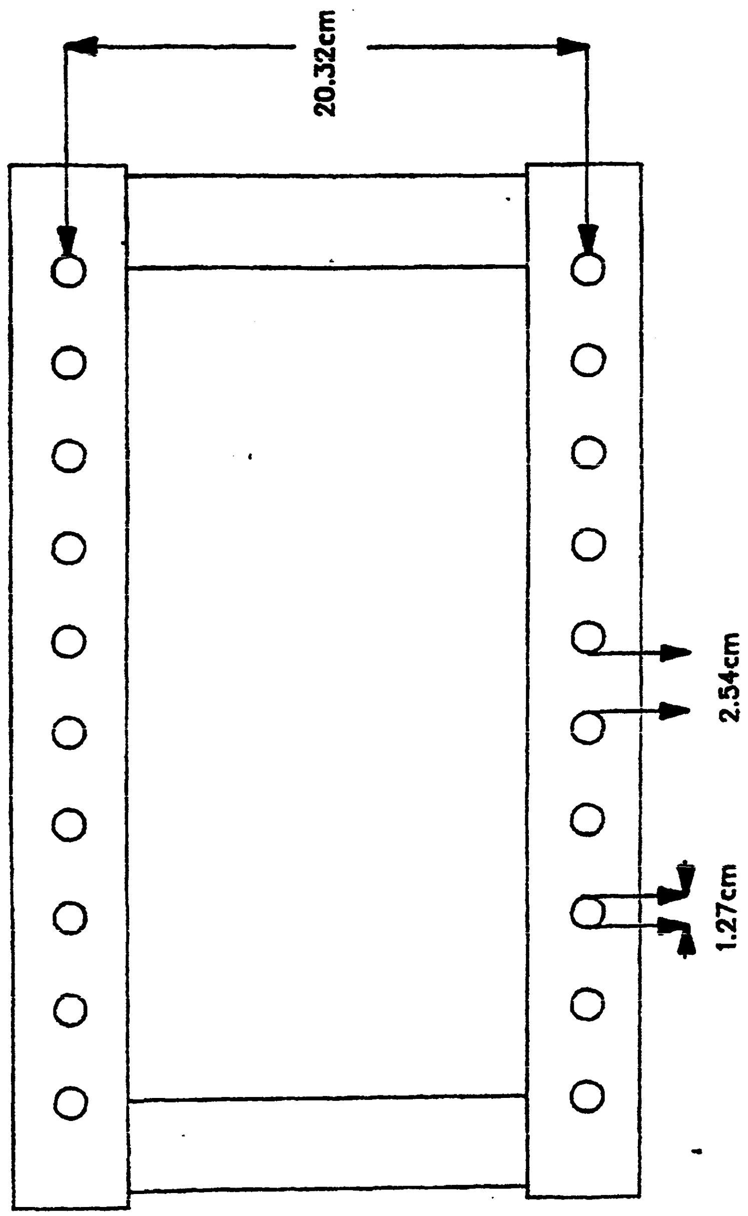
8 gritchklomp ....

9 bloangrapst ....

10 nolcrid ....

Appendix U

A diagram of the Annett pegboard



Appendix V

A Histogram of Diff (verbal factor - non-verbal factor) with a superimposed normal curve (.)

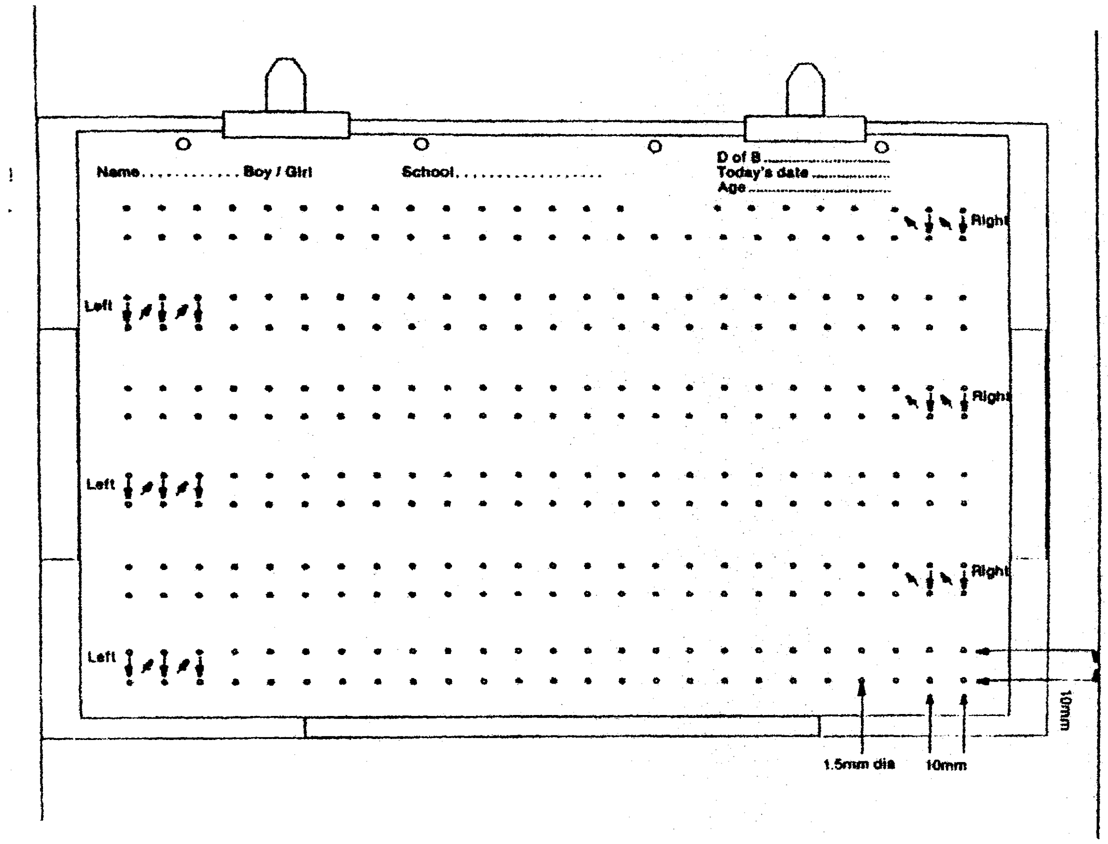
```
Count      Midpoint
    0         -6.00 ª
    0         -5.25 ª
    2         -4.50 ªÜ
    0         -3.75 ª.
   10         -3.00 ªÜÜÜ:Ü
   16         -2.25 ªÜÜÜÜÜÜÜÜ  .
   48         -1.50 ªÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜ:Ü
   74          -.75 ªÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜ:ÜÜÜ
   93           .00 ªÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜ:ÜÜÜÜÜÜÜÜ
   64           .75 ªÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜ .
   29          1.50 ªÜÜÜÜÜÜÜÜÜÜÜÜÜÜÜ         .
   22          2.25 ªÜÜÜÜÜÜÜÜÜÜ:
   15          3.00 ªÜÜÜ:ÜÜÜÜ
    1          3.75 ª:
    3          4.50 ªÜÜ
    0          5.25 ª
    0          6.00 ª
                     I....+....I....+....I....+....I....+....I....+....I
                     0         20        40        60        80        100
                                 Histogram frequency
```

DIFF

Mean	1.6256E-16	Std dev	1.414	Minimum	-4.506
Maximum	4.764				

Appendix W

A diagram of the Target Circles (on stiff A4 Paper supported by Board) for the Hole Punching Task



Appendix X

A Histogram of Diff (nonword rhyme decision minus Benton phoneme discrimination) with a superimposed normal curve (.)

```
DIFF

    Count   Midpoint
        0      -5.50 ³
        1      -4.75 ³Û
        1      -4.00 ³:
        3      -3.25 ³ÛÛ.
       14      -2.50 ³ÛÛÛÛÛÛÛ.
       29      -1.75 ³ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ  .
       76      -1.00 ³ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ:ÛÛÛÛÛÛÛÛÛ
       86       -.25 ³ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ:ÛÛÛÛÛ
       74        .50 ³ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ:Û
       41       1.25 ³ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ    .
       27       2.00 ³ÛÛÛÛÛÛÛÛÛÛÛÛÛÛ.
        6       2.75 ³ÛÛÛ  .
        7       3.50 ³Û:ÛÛ
        3       4.25 ³ÛÛ
        0       5.00 ³
        1       5.75 ³Û
        0       6.50 ³
                     I....+....I....+....I....+....I....+....I....+....I
                     0         20        40        60        80        100
                               Histogram frequency
-------------------------------------------------------------------------------
Page  37                          SPSS/PC+                             11/11/98

DIFF


Mean      1.8534E-16      Std dev        1.414      Minimum        -4.427
Maximum        5.554
```