PHONOLOGY AND LEARNING TO READ IN NORMAL AND HEMIPLEGIC CHILDREN

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Abstract

A cognitive-developmental perspective was adopted, within a longitudinal framework, in order to address issues pertaining to the development of reading and related cognitive processes in normal and hemiplegic children.

Thirty eight normal children were studied longitudinally between the ages of four and six years. It was established that phonological awareness comprises two separate and relatively independent subskills, those of rhyming and segmentation; these exerted differential influences over early reading and spelling development. Segmentation, interacting with the children's knowledge of letter names, had a profound bearing on progress during the first year of learning to read and spell. In the following year, the reading results were consistent with the children having consolidated a sight vocabulary. However, spelling remained phonologically bound, with both rhyming and segmentation exerting a significant effect. Thirty six children from the normal sample participated in a small experimental (training) study looking at children's early use of analogy in reading. The children at age six were able to make analogical inferences, enhanced in the presence of a clue word, provided they had some rudimentary reading skills.

Thirty eight young children having congenital unilateral brain lesions were studied longitudinally and their performance on a range of cognitive measures compared to that of 20 (medical) controls. The absence of laterality effects on Verbal IQ supported the hypothesis of the equipotentiality of the two hemispheres for the development of at least gross language skills. However, Performance IQ was selectively impaired, irrespective of the side of lesion. It is suggested that verbal skills are prioritised in the remaining intact neural space, but at the expense of visuospatial functions. Over and above these trends, the presence of seizures produced generalised impairment of cognitive functioning, and, in the case of left hemisphere insults, additional selective language deficits. The hemiplegic children's phonological and reading patterns were analysed in terms of the model developed with the normal sample. The strong phonology-reading connection evident in the normal children was also demonstrated in the seizure-free children with right hemisphere lesions, but appeared to be reduced in the children with left hemisphere lesions.

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Chapter 1

Beginning Reading

1.1 Developmental Models of Early Reading Acquisition

There have been numerous attempts to explain how children acquire early reading and spelling skills. One approach is to propose that they proceed through a series of discrete stages, each drawing on knowledge built up in the previous stages, to explain the development of increasingly complex and refined skills. Three stage models, having particular relevance to the issues addressed in this thesis, will be considered, and their similarities and differences compared. An alternative perspective on early literacy development will then be introduced.

The first model is that proposed by Marsh, Friedman, Welch and Desberg (1980), which draws on Piagetian theory. There are four stages:
1) **The Linguistic Guessing Stage** in which the child reads a few familiar words by rote, and "guesses" at others using context cues. This stage corresponds to Piaget's "difficulty in decentering" concept whereby the young child focuses on prominent details of a word but makes no attempt at a systematic analysis of it. More recently, Tunmer (1989) has made reference to the decentering notion to explain his findings on metalinguistic abilities and their relation to early reading development.
2) **The Discrimination Net Guessing Stage** whereby visual graphic cues come into play when a new word is encountered, so that errors tend to show some orthographic similarity to the printed word (though often only the first letter).
3) **The Left to Right Sequential Decoding Stage** corresponds to Piaget's Concrete Operations stage and refers to the point at which the child begins to make systematic use of letter-to-sound correspondence rules.
4) **The Hierarchical Decoding Stage** in which higher order e.g. conditional rules, together with the use of analogy, emerge and even override the grapheme-to-phoneme correspondence rules.

Uta Frith's 1985 model of reading and spelling development, which is a development of the approach taken by Marsh et al., postulates the existence of three stages:

1) **The Logographic Stage** whereby words are remembered according to their salient visual features.

2) **The Alphabetic Stage** in which the child uses phoneme-to-grapheme (not just sound-to-letter) correspondences, initially in spelling and then later in reading.

3) **The Orthographic Stage**, which appears first in reading and then in spelling, depends on the child developing a recognition memory for graphemic clusters e.g. tion, ove.

Finally Ehri's 1987 Theory of Printed Word Learning also describes three stages:

1) **Visual Cue Reading** in which salient visual cues seen in and around a word are linked to its meaning and pronunciation by rote memory.

2) **Phonetic Cue Reading** which may be further subdivided into first, **A Semi-Phonetic Stage** in which the child produces "partial" readings and spellings based on salient phonological characteristics and letter names (letters and consonant clusters are frequently omitted). When the child develops more reliable phonemic segmentation ability and complete alphabetic knowledge, he or she progresses to the **fully phonetic** stage where accurate phonic approximations are made when reading and spelling.

3) **A Morphemic Stage** during which there is the adoption of strategies based on lexical and morphemic word patterns.

In Ehri's model, the child also builds up a lexicon of specific word spellings alongside each of the three stages. This process is independent of the use of complex orthographic knowledge which characterises her later morphemic stage. Ehri (1992) has revised and further developed her model in the light of recent evidence, and to take account of the increasing influence of connectionist models (See Section 1.2).

There are substantial similarities between the three models. They all propose that each child must pass through the same stages in the same order. Second, initial reading begins with the child paying little attention to graphic cues, but gradually incorporating more of these up to the point where correspondence rules take over. Finally, it is generally agreed that the use of morphemic and complex orthographic information is adopted in the final stage of all three models.

It is worth commenting on the differences between the stage models discussed. Frith's model emphasises the influence reading and spelling have on each other, and also attempts to explain specific reading problems e.g. dyslexia as a deviation from normal development. In her view, dyslexics are "arrested" in the early **logographic** stage and so their reading remains logographic and their spelling non-phonetic; examples of logographic errors would be reading "bowl" as "blow" and "cask" as "cash", while examples of non-phonetic spelling would be writing "fine" for "fish" and "gorhy" for "geography" (Snowling, Stackhouse and Rack, 1986). Ehri's model is different to the others in that it introduces the notion of specific word learning that occurs throughout the three stages and which is independent of, but nonetheless interacts with, other stage-related processes. Marsh et al. aim to explain literacy development in terms of basic underlying (Piagetian) cognitive constructs, and further bring in the use of analogical routes to reading and spelling in their final stage.

Stage models of literacy development (or indeed cognitive development in general) have met with substantial criticism from various quarters. Goswami and Bryant (1990) point out that such models have great difficulty in explaining the "cause" of each stage i.e. how children get from one stage to the next. What prompts stage transition is crucial to knowing how to teach children to read. Also, stage models cannot readily explain individual difference in children's reading except to say that some children proceed through the various stages at a slower rate than others. It is thus easy to explain the reading backwardness of slower learning children, but it is harder to account for the qualitative differences observed in say brighter dyslexic children. For instance, dyslexics tend to have greater difficulty reading nonwords than do reading-age-matched controls who are presumably at the same stage of literacy development (see Rack, Snowling and Olson, 1992, for a review).

Stuart and Coltheart (1988) demonstrated in their longitudinal study that not all children pass through the same sequence of stages. They found that children who were phonologically skilled before they learned to read (i.e. as preschoolers) used phonological strategies from the beginning. In other words they did not proceed through an initial logographic stage at all.

Wimmer and Hummer (1990) have also cast doubt on the necessity of there being an initial logographic stage. They have suggested that this stage may be induced as a consequence of teaching styles and procedures (i.e. look-and-say followed by phonics), and that it may also arise as a consequence of the poor fit between phonetic and graphemic representations in English. They presented evidence to show that first graders whose language of education is phonologically transparent (in this instance, German) rely on alphabetic strategies for both reading and spelling right from the very beginning. First, they demonstrated that most of their subjects were able to read unfamiliar nonwords. Second, the children's reading errors consisted mainly of nonwords beginning with the first letter of the target word, as opposed to an absence of reading attempts or the production of real words having a visual similarity to the target (which would be expected if the children were confined to logographic reading strategies). Finally, both reading and spelling performance were strongly predicted by knowledge of grapheme-phoneme correspondence. The authors concluded that the logographic strategy is of limited importance when the writing system is phonologically transparent, and when the instructional approach fosters an awareness of grapheme-phoneme correspondence.

Frith and Ehri have conceptualised the logographic stage as being of relatively brief duration. Others have doubted its existence, or at any rate its relevance, for all beginning readers (Wimmer and Hummer, 1990, Stuart and Coltheart, 1988). Seymour and Elder (1986) and Seymour (1987) have, however, credited the logographic stage with greater prominence and durability than either Frith and Ehri or their doubters would permit. Seymour (1987) conceptualises the logographic and alphabetic stages as initially developing in parallel, with their resultant lexicons remaining as permanent features of a word recognition system. In this view, the logographic stage, which is based on visual cues, expands progressively into a large direct access lexicon. The orthographic lexicon is seen as an expansion of the alphabetic lexicon; it is transformed from a system that recognises only isolated phonemes into one able to process more complex graphemic clusters. The two lexicons are thought to show progressive merging over time so that integrated word recognition is ultimately achieved.

Goswami and Bryant (1990) propose an alternative sort of developmental model which centres around three causal factors:

1) The presence of preschool phonological skills, especially rhyming;
2) The learning of an alphabetic script;
3) The linking of reading and spelling as interactive processes.

What Goswami and Bryant are describing is not a series of discrete stages, but a process whereby children gradually get better at strategies that they use from the start. This is in agreement with the observation of Stuart and Coltheart (1988) i.e. that phonological processes are used by many children right from their first experiences of print. The same may be true of other word attack strategies such as analogy. Goswami (1986) has demonstrated that children as young as six years can adopt an analogical route to reading, but it probably does not reach a refined and sophisticated level of usage until about age 10 (Marsh, Friedman, Welch and Desberg, 1980).

1.2 Dual-Route Models of Reading and Spelling Development

In the previous section, stage models of early literacy development were critically reviewed and an alternative causally based model introduced. A related process-based perspective draws on the dual-route model of skilled adult reading. This model has undergone a series of developments and refinements over the last 10-15 years in the light of newly available evidence.

In the "strong" version of the model (Henderson, 1982, 1985), there are assumed to be two independent routes to accessing the meaning of printed words. One possibility is **direct access** in which the letter identities of a printed word are used to access its orthographic representation in the mental lexicon. The whole word orthographic representation is in turn used to access the word's semantic representation. This route is assumed to be visually based, non-phonological and reliant on rote memory. It applies to the reading of familiar and irregular words. The second possibility is **indirect access** in which the letter identities of a printed word are first segmented into graphemes, after which a phonological representation is assembled by applying grapheme-to-phoneme correspondence rules. The semantic lexicon is accessed through the phonological representation. This route is applicable to the reading of unfamiliar but regular words and nonwords. The assumption of the independence of the two routes has received support from the neuropsychological literature, in particular research into acquired dyslexia. Acquired phonological dyslexics (Shallice, 1981) are able to read words by the direct lexical route but have great difficulty with the indirect or assembled route to reading. Consequently, low-frequency regular words and nonwords present them with problems. Conversely, acquired surface dyslexics (Beauvois and Derouesne, 1981) are impaired in their use of a lexical route and thus become heavily dependent on the application of grapheme-to-phoneme correspondence rules. Irregular words are "regularised" in reading but regular words and nonwords present no difficulty.

A major limitation of the standard or strong version of the dual-route model is that the phonological representation can only be assembled by the use of grapheme-to-phoneme correspondence rules. These rules explicitly deny any role for lexical knowledge in the construction of a phonological representation. However, there is substantial evidence for the role of lexical knowledge in the reading of words that can only be accessed via the indirect route e.g. nonwords. Campbell (1985) has demonstrated that children's and adults' nonword spelling is biased by real words they have previously heard. Thus, for the nonword /fri:t/, those subjects "primed" with the aurally presented word "neat" were more likely to spell the nonword "freat", while those primed with "feet" typically wrote "freet".

Evidence such as this has prompted a reconsideration of the dual-route model. An alternative version might involve retaining the distinction between lexical and non-lexical routes but expanding the scope of the letter. One such revision (Patterson and Morton, 1985) employs an Orthographic-to-Phonological Correspondence (OPC) system which does not restrict orthographic units being mapped only onto phonemes. These authors permit correspondence to larger orthographic units called "bodies", which in alternative terminology are "rimes" (Treiman, 1985) i.e. vowel plus end consonant segments; for instance, in the words "truck" and "train", the bodies or rimes are "uck" and "ain", respectively. Thus analogical processes in reading enter the system, in addition to the application of grapheme-to-phoneme correspondence rules. The modified dual-route model allows for interaction between the lexical and non-lexical routes; this would seriously violate the assumptions of the stronger version of the model. Ellis and Young's modified dual-route model (1988) also incorporates an analogical system which would appear to involve both the visual input lexicon (i.e. matching of the presented word to similar familiar words already in the lexicon), and phonological processing required for recoding and blending the orthographic units within the word. Modified dual-route models accommodate far more research evidence than do the stricter versions and take better account of the complexities inherent in the reading process.

The dual-route model was developed to explain adult skilled reading and is consistent with much of the neuropsychological data. However, it would be a mistake to assume that it can be applied unreservedly to an understanding of children's literacy development. Indeed, the model presents considerable difficulties when viewed from a developmental perspective. While the use of both direct and indirect access procedures is usually associated with fluent reading skill, reliance on only one procedure is thought to characterise a level of reading competence lower down the developmental continuum (Jorm and Share, 1983). A major issue in research on beginning reading is whether reading skill acquisition starts with direct or indirect access. The implications for the choice of instructional methods in early reading (i.e. look-and-say or phonics) are considerable, not to say controversial. Barron (1986) reviewed the evidence for direct-to-indirect versus indirect-to-direct hypotheses, and concluded that there was not overwhelming support for either. Most importantly, there was accumulating evidence in favour of both direct and indirect routes being used from the start. Stuart and Coltheart (1988) have shown that there are individual differences in children's capacity to make use of a phonemic, as opposed to a visual strategy, right from the time they begin reading. Their evidence included the fact that phonological knowledge and sound-to-letter knowledge, measured prior to entering school, combined to predict reading age after only nine months of schooling. While a direct route of access may be preferred by many young children in reading, they are more willing to adopt an indirect phonemic based strategy for their first spelling attempts (Bryant and Bradley, 1980). Jorm and Share (1983) present a rationalisation for this confused picture by proposing that beginning and fluent readers use both direct and indirect access routes, but that the probabilities attached to the use of the two procedures may be unequal and change with age and in accord with factors such as individual preference or type of task.

Even with the increased flexibility afforded by the Jorm and Share modification, two main problems remain for the dual-route model and its explanation of beginning reading. These are comprehensively and critically discussed by Barron (1986). First, while the direct and indirect access routes appear to cover all the words children might encounter (i.e. regular, exception, nonwords), the model cannot readily characterise the process children employ in attempting to read words during the transition from being non readers to becoming readers. Orthographic units children use, particularly before they have had much formal reading instruction, may be different from those identified within either route of the dual-route model. The model cannot easily account for the performance of beginning readers who tend to treat words, not as complete sequences of letters, but as partial graphic configurations with which they associate whole word pronunciations (Ehri and Wilce, 1985). The second major criticism from the developmental perspective is that it is hard to see how beginning readers could make much progress in acquiring an orthographic lexicon without it being influenced by their knowledge of phoneme-to-grapheme rules. Waters, Seidenberg and Bruck (1984) found that grade three children read aloud high-frequency regular words more accurately than low-frequency regular words, even though many of the same grapheme-to-phoneme correspondence rules applied to both categories of words. This suggests that the strength with which children acquire word specific orthographic knowledge is a function of the number of times they apply correspondence rules to particular words.

The point that direct access to the orthographic lexicon might remain at least partly dependent on the child's knowledge of letter-sound relationships is developed by Ehri (1992). She questions why, in the sight reading of familiar words, the process should be a purely memory based visual one when for most children letter-sound relations were used initially to learn to read the words. It seems surprising that the invaluable information contained in these relations should completely drop out when memory takes over. Also, even for irregular words, there are opportunities for children to take advantage of systematic relations between at least some of the sound-to-letter correspondences (few irregular words are so constructed that looking for phoneme-to-grapheme consistency has no role to play). Instead of a non-phonological visual route, Ehri proposes that a visual-phonological route is more parsimonious with the existing evidence. She suggests that children retain an awareness of the letter-sound relations within a word after it has been learned so that these links can participate in a reading by memory operation. Specific connections between visual cues within the word (sequences of letters, not phonemes) and its pronunciation stored in memory are set up. The connections are formed out of the reader's knowledge of sound-letter correspondences and of orthographic regularities. This process is different to, and faster than, the phonological route because it omits the intermediate stages of applying grapheme-to-phoneme correspondence rules and of phonological matching to the word in the semantic lexicon. The slower indirect route is likely to be used when a new word is encountered. But once it has been seen and recoded by this route several times, the translation and phonological matching steps drop out leaving direct links between the spelling and its pronunciation. Ehri goes on to present experimental evidence that favours this model over the traditional dual-route approach. For instance, within artificial orthography, systematically spelled words are read faster than arbitrarily spelled words when both have been learned to the point of becoming sight words e.g. "jrf" for "giraffe" as opposed to "wbc" (Ehri and Wilce, 1985). The dual-route model would not predict such a difference, whereas Ehri's model recognises the facilitative effect of having systematic sound-letter relations.

Ehri has expanded her earlier stage model of printed word learning to accommodate her reconceptualisation of sight word reading and to bring it into line with a connectionist framework (see below). Sight word reading develops in three phases. The first, visual cue, phase adopts the visual route as described in the conventional dual-route model; salient visual cues seen in and around the word are linked by rote memory to its meaning and pronunciation. In the second phase, phonetic cue learning, children learn about letter names or sounds and use these to form systematic visual-phonological connections between letters and sounds. To begin with, the connections are incomplete as only some letters (usually initial and/or final ones) are linked to sounds. When readers' phonemic segmentation and recoding skills improve, they are in a position to form complete visual-phonological connections in learning to read sight words, and so enter the cipher sight word reading phase.

1.3 Connectionist Models of Reading Development

Van Orden, Pennington and Stone (1990) discuss in depth the dual-route model's key assumptions, their limitations and the evidence countering them, before describing an alternative framework that forms the basis of **connectionist (or parallel distributed processing) models**. These are based on large scale computational programmes that simulate aspects of reading performance. Van Orden et al. make reference to a "covariance learning hypothesis" that concerns the acquisition of mappings that relate one representation to another. These are conceptualised as input-output codes which initially are associated on a stimulus-specific basis. Eventually, rule-like behaviour emerges from the reflection of statistical regularities distributed across the input-output pairs.

One model of this type that has been implemented is described by Seidenberg and McClelland (1989), and its relevance to beginning reading discussed at length by Adams (1990). This connectionist model aims to provide a unified account of reading acquisition, its skilled performance and its breakdown (as in dyslexia). Skilful reading is seen as the product of the coordinated and highly interactive processing of three types of information: orthographic, phonological and semantic. In this model, orthographic and phonological strings are connected without making explicit use of spelling-to-sound correspondence rules.

The Seidenberg and McClelland model consists of a set of orthographic units that code letter strings, a set of phonological units that code phonological information, and a set of hidden units that connect the orthographic and phonological units. It is accepted that there is also a semantic processor that codes meaning, but this has not yet been implemented within the model. Before training, all orthographic units are connected to all hidden units, and all hidden units are connected to all phonological units. These connections, together with the hidden units, carry weights that govern the spread of activation across the units. It is these weights that encode the model's knowledge about written English. The orthographic and phonological codes are represented as patterns of activation across a large number of primitive representational units. Phonemes are encoded as a set of triples, each specifying a phoneme and its flanking phonemes; for example, the word "make" consists of the phoneme triple /mAk/ and is coded as _mA, mAk, and Ak_. Orthographic representation is also in the form of triples, this time of letters, with each unit consisting of 10 possible first letters, 10 possible second letters and 10 possible third letters.

The model is trained using English monosyllabic words. Before training, the weights between the hidden units and the orthographic and phonological units are set randomly at intermediate strength. When the letter string is presented, an entirely random pattern of activation is sent from the orthographic to the phonological processor via the hidden units. The resulting pattern of activation on the phonological units is then compared to the correct pattern for the pronunciation of the target word. A learning procedure adjusts the weights of the connections in the network in proportion to the extent that this will reduce the mismatch between the actual and correct patterns of excitation. With further trials, the weights continue to be adjusted in such a way as to increase the probability of the word being "read" correctly.

The Seidenberg and McClelland model has been successful in simulating a number of different aspects of reading performance, and has been found to generate acceptable pronunciations for many novel items, including nonwords. Although the model emphasises incremental learning, it is worth noting that a connectionist approach does not preclude describing the development of reading in terms of a series of stages (Brown and Watson, 1991); it is, therefore, not necessarily incompatible with stage models (as indeed Ehri, 1992, has attempted to show).

The connectionist view of the phonological processor may, however, require further development and refinement before it is able to accommodate certain findings from research into beginning reading. One inadequacy highlighted by Hulme, Snowling and Quinlan (1991) is that the Seidenberg and McClelland model pays no attention to the vast body of evidence on early phonological awareness and its powerful predictive effect on subsequent reading development (see Section 1.4 below). Indeed, the model assumes that the phonological store is entirely unstructured to begin with. However, it is clear that children come to the task of reading with highly developed phonological representations. Hulme et al. propose that a way to resolve this would be to incorporate a pre-structured phonological store that would facilitate learning the mappings of orthographic onto phonological representations. Those children having poorly specified phonological stores would be expected to have difficulty learning to read.

1.4 Phonological Awareness and Beginning Reading

Over the last 10 - 15 years, a vast body of evidence has accumulated to support the view that phonological awareness has a powerful influence over early reading development. Phonological awareness refers to the child's sensitivity to speech sounds within words i.e. his or her realisation, at a metalinguistic level, that words can be broken down into constituent sound segments and sequences. Because phonological awareness and its relation to beginning reading is a primary focus of this thesis, an extensive review of the evidence is attempted, and is subdivided for clarity and ease of presentation.

1.4.1 Phonological Awareness and its Contribution to Early Reading Development

Correlational and longitudinal studies conducted over the last decade have established that phonological awareness, even when assessed in preschoolers, is a powerful predictor of progress in beginning reading. Tasks devised to measure children's phonological awareness may be divided into four main types:

(i) Syllable and Phoneme Segmentation Tasks: One of the earliest tasks developed to assess children's abilities to segment words into their constituent sound strings is the "tapping test" devised by Liberman, Shankweiler, Fischer and Carter (1974). They found that six-year-olds' capacity to count phonemes within words by tapping them out with a dowel predicted their reading levels one year later. These findings have been confirmed in longitudinal studies carried out by Mann (1984) and Tunmer and Nesdale (1985). Other segmentation tasks have required the child to say the initial syllable or phoneme in a given word e.g. "pen" in "pencil", and "p" in "pen" respectively (Fox and Routh, 1975), or to finish off the final syllable or phoneme in a word represented by a concrete object (Stuart and Coltheart, 1988). Cataldo and Ellis (1988), in their longitudinal study of early reading development, demonstrated that the ability to segment single syllable words into two or three parts contributed first to spelling and then at a later stage to reading.

(ii) Phoneme Manipulation Tasks: The task used most frequently is that of phoneme deletion i.e. requiring the child to omit the initial phoneme of a presented word e.g. "cat" without the "c" says "at" (Bruce, 1964, Calfee, 1977). Success on this task, rarely evident in preschoolers and then demonstrable only with careful teaching (Rosner, 1974, and Calfee, 1977), is an excellent predictor of later reading development. Share, Jorm, Maclean and Matthews (1984) found kindergartners' phoneme deletion ability to be the best predictor of reading measured one year later, accounting for 39 percent of the variance. Phoneme deletion scores were also strong predictors of reading success in the large scale longitudinal study carried out by Lundberg, Olofsson and Wall (1980).

(iii) Sound Blending Tasks: In blending tasks, the examiner provides the phonemes of the word and the child is asked to put them together e.g. "c - a - t " blends to yield "cat". The capacity of sound blending to predict reading success when administered to beginning readers has been demonstrated in studies by Lundberg, Olofsson and Wall (1980), and Perfetti, Beck, Bell and Hughes (1987).

(iv) Rhyming (including Oddity) Tasks: Rhyming and its effects on reading has been largely championed by Bryant and his colleagues in a series of studies conducted in the mid-to-late 1980s. MacLean, Bryant and Bradley (1987) found that knowledge of popular nursery rhymes, assessed in preschoolers, strongly and specifically predicted the later development of more abstract phonological skills and of emergent reading abilities. Bradley and Bryant (1983) tested children's ability to detect rhyme using an oddity task in which their subjects were asked to isolate the odd-word-out in a sequence of three or four e.g. "doll, hop, top" i.e. the word that did not rhyme with the others (Bradley Test of Auditory Organisation, Bradley, 1980). This test given to four- and five-year-old non-readers proved a powerful predictor of reading at age six to seven years, even after controlling for the effects of age, IQ, and memory load. Reservations have, however, been expressed about the appropriateness of the odd-word-out test, both as an accurate measure of rhyming ability and in terms of its suitability for use with very young children. Wagner and Torgesen (1987) point out that this test is a highly complex one, containing a heavy working memory component. Bradley and Bryant attempted to control for the memory factor, which in itself may substantially relate to early reading capability (see Section 1.5 of this chapter), by entering simple memory span measures ahead of the odd-word-out scores in their multiple regression analyses. However, as Wagner and Torgesen have indicated, this attempt at statistically controlling for the potentially confounding effects of memory may not have been either appropriate nor sufficient. A simple memory span score is unlikely to be a valid measure of the memory demands of the oddity test which requires the simultaneous maintenance of a list of words in short-term memory while performing the cognitive operations required for selecting the odd-word-out. More direct and unconfounded measures of rhyming ability may be necessary to clarify the exact relationship between rhyming and early reading.

It is clear that phonological awareness can be measured in a number of ways. Are the different types of tasks assessing different aspects of phonological development or are they merely tapping a single underlying global skill? Stanovich, Cunningham and Cramer (1984) and Wagner and Torgesen (1987), who carried out a Principal Components Analysis of Lundberg et al.'s extensive 1980 data, have argued that the most commonly used tests of phonological awareness appear to be measures of a single construct or underlying ability rather than of multiple and unrelated skills. However, Yopp (1988) uncovered two factors from a Principal Components Analysis (with oblique rotation) of 10 phonological awareness tasks given to 96 kindergarten children. The factors were highly correlated, and seemed to reflect two levels of difficulty which Yopp termed Simple and Compound Phonemic Awareness. Simple awareness required only one cognitive operation, while compound awareness involved two operations and placed a heavier burden on memory. In the studies by Stanovich et al. and Yopp, the factors obtained significantly contributed to the children's performance on reading tasks.

It is clear that some phonological awareness tasks are better predictors of reading ability than are others. Adams (1990) draws attention to the fact that, in general, the more difficult and later acquired skills (like phoneme segmentation and manipulation) yield stronger predictions of reading development than do the earlier acquired skills (like nursery rhyme knowledge, syllable segmentation and sound blending). It could be the case that different phonological awareness skills are relevant to the reading process at different points in its development. It may well be that the way forward in further research is to evaluate longitudinally the effects of different levels and types of phonological awareness on different aspects of early literacy development (e.g. reading versus spelling, whole word recognition versus phonic decoding versus use of analogy).

While phonological awareness clearly exerts a profound influence over subsequent reading development, this does not imply that the direction is necessarily one-way. Indeed there is good evidence that learning to read affects the development of phonological awareness, especially of the more advanced skills of phoneme segmentation and manipulation. Liberman et al. (1974) demonstrated that, while most preschoolers can segment words into syllables, very few can readily segment them into phonemes. The more sophisticated stage of phoneme segmentation is not reached until the child has received formal reading instruction i.e. until well into the first year of learning to read. Children appear to require exposure to letter-sound relationships before they can proceed further along the continuum to advanced phonological awareness. Indeed the specific method of reading instruction can have a direct bearing on children's phonological awareness. Alegria, Pignot and Morais (1982) looked at syllable and phoneme segmentation ability in two groups of six-year-olds; one group had a phonic-based method of reading instruction, the other a whole word approach. The phonic-trained children did better on the phoneme segmentation task than did the whole-word-trained group, but there was no difference for the syllable segmentation task. Longitudinal studies (Cataldo and Ellis, 1988, and Ellis, 1990) have shown, using Path Analysis techniques, that not only does phonological awareness predict later literacy development, but that reading, and perhaps even more importantly spelling, promotes phonological awareness.

Further evidence for reading affecting phonological development comes from studies of adult illiterates and from children taught non-phonological based written languages. Morais, Cary, Alegria and Bertelson (1979) found that Portuguese adult illiterates had much more difficulty in deleting or adding phonemes within words than did those who had already benefitted from an adult literacy programme; they concluded that the ability to analyse sounds depends to a significant extent on the experience of learning to read. Of greater developmental relevance is Mann's (1986) study in which she compared the performance of six-year-old Japanese and American children on a phoneme awareness task. The Japanese children, who were being taught a syllable-based written language, performed below the level of the American children on the phoneme awareness task. The available evidence suggests that there is a two-way interactive process between phonological awareness and learning to read. As Bryant and Goswami (1987) point out, it may be that some forms of phonological awareness pre-date and facilitate reading development, while others are caused, or at any rate influenced, by exposure to print.

1.4.2 Phonological Awareness and the Onset-Rime Distinction

While most studies have emphasised phonological awareness as the capacity to break words into constituent syllables or phonemes, there is a third, and perhaps intermediate way, of looking at the breakdown. This is the onset-rime distinction, first described and demonstrated in young children by Treiman (1985). The onset of a single syllable word is its initial consonant or consonant cluster, while its rime is the vowel and the consonant/s which follow it. Treiman showed that four- to six-year-olds could more easily identify a target sound e.g. "s" when it formed the complete onset of a nonword e.g. "s-an" than when it formed only part of the onset e.g."s-na". Kirtley, Bryant, MacLean and Bradley (1989) found that five-year-olds could categorise words quite easily if this involved isolating the word's onset but found it very difficult when they needed to break up the word's rime. In a training study by Wise, Olson and Treiman (1990), beginner readers remembered how to read words better when pronunciations and spellings were segmented into onset-rime units during learning e.g. f-ork, sl-ip, than when segmented in other ways e.g. fo-rk and sli-p. Treiman (1992) has demonstrated that young children's spelling errors often reflect their failure to appreciate the phonemic structure within onsets and rimes. Six-year-olds frequently spell a consonant blend onset like /bl/ as b. They can spell syllable initial /b/ as b and syllable initial /l/ as l, but they are unable to spell syllable initial /bl/ as b followed by l. They consider /bl/ to be a unit rather than a sequence of two separate phonemes. Thus, young children can demonstrate a good awareness of the onset-rime breakdown of real- and non-words while being unable to split them further into their finer phoneme constituents. Onset-rime sensitivity would appear to follow syllable awareness but to precede the ability to break words into phonemes. However, in contradiction to this, is the finding of Seymour and Evans (1991) that the six-year-old children in their sample found it easier to divide words phoneme-by-phoneme than into onset and rime. These authors suggest that children's preference for one method of segmentation over another may be influenced by instructional style.

Bryant and Goswami have taken Treiman's work on the onset-rime distinction further. Firstly, they have claimed that onset-rime awareness forms a basis for children's ability to make use of analogical strategies in early reading and spelling (Goswami and Bryant, 1990). In a series of carefully designed and controlled experimental studies, Goswami (1986, 1988, 1990) has demonstrated that young children, even pre-readers, can use a clue spelling like "beak" to help them read new words such as "weak" and "peak" which share the clue word's rime. Goswami (1991) has further shown that children find it easier to make analogies when the onset-rime distinction within a word is preserved. She compared children's use of analogies when reading new words with either shared consonant blends at the beginning such as <u>tr</u>im, <u>tr</u>ap (where the blend corresponds to the complete onset), or at the end as in wi<u>nk</u>, ta<u>nk</u> (where the blend is part of the rime). The children made more analogies from the beginning than the end blends; this was attributed to the former preserving the onset-rime boundary.

Goswami (1986) has claimed that prereading six-year-olds can be taught to apply analogical principles in reading. It follows that the ability to make use of analogy is not dependent on existing reading skills, and that it precedes the adoption of phonological decoding strategies. However, Ehri and Robbins (1992) have suggested that children need some decoding skill i.e. knowledge of grapheme-phoneme correspondence before they can read words by analogy. They found that, while six-year-old children with established decoding skills were able to read analogy words after being trained to criterion on a series of clue words, similarly aged-children with limited decoding skills (novices) did not learn to read analogy words any more easily than control words during the practice trials. In short, incomplete lexical knowledge that does not contain sufficient letter detail to identify rime units will not favour reading by analogy. Ehri and Robbins have cautioned against premature and excessive enthusiasm for the teaching of analogies to very beginning readers.

This view is echoed by Bruck and Treiman (1992) in their study of six-year-old children allocated to one of three different analogy training groups: a rime training group for which the target word shared the rime of the clue word e.g. "pig" and "big"; a consonant-vowel training group for which the target word shared the initial consonant and vowel of each clue word e.g. "pig" and "pin", and; a vowel training group for which the target word shared the vowel but none of the consonants for each clue word e.g. "pig" and "bit". The results suggested that learning to pronounce words on the basis of rimes worked well at first, during the analogy testing trials. However, this method did not yield the best long-term results. Rather, it was the children in the vowel training group who achieved the best long-term results, both in remembering the real words they had been taught, and in generalising the training to nonwords. Bruck and Treiman concluded that children need instruction not just in the relations between groups of graphemes and groups of phonemes, but also in the correspondences between single graphemes and single phonemes.

Finally, Goswami and Bryant (1990) have argued for a close relationship between rhyming ability and children's awareness of the onset and rime units within words. After all, words that share the same rime also necessarily rhyme with each other. Goswami (1990) found that children's rhyme awareness, as measured by Bradley's oddity task, was more closely related to their success in making analogies than was their performance on a phoneme deletion task. Goswami and Mead (1992) have extended these findings to show that rhyme awareness is associated with the ability to make end analogies (e.g. "beak-weak"), while more complex tasks of phonological awareness, such as a final consonant deletion task, are related to the making of beginning analogies (e.g. "beak-bean"). The authors concluded that rhyme awareness reflects an awareness of onset-rime boundaries within words, while final consonant deletion tasks, that break up the rime unit, tap the more advanced skill of segmenting words at boundaries other than those of onset and rime. These studies were cross-sectional and, therefore, do not speak to the predictive relationship between rhyming skill and the use of analogies. Clearly, longitudinal data, in which rhyming measures are obtained prior to the demonstration of analogy effects, are needed to provide evidence in support of a causal relationship between rhyming and the use of analogy in reading.

The research on rhyming, onset-rime breakdown and children's use of analogy in reading offers a sound paradigm for looking at the link between a specific type of phonological awareness and the process through which it influences a later and again specific aspect of reading development. The evidence is as yet incomplete, since longitudinal studies of rhyming and analogy are still lacking. However, this approach is one which, if also applied to other phonological awareness skills e.g. segmentation or blending and to other reading strategies e.g. phonic decoding could greatly advance our understanding of the specific processes involved in early literacy development. The implications for the adoption of focused teaching methods at preschool and infant school level are considerable.

1.4.3 Phonological Awareness, Its Interaction with Other Factors and Reading Development

The complexities of reading development are such that it seems highly probable that, not only are phonological awareness and reading linked in a reciprocal two-way interaction, but there are likely to be other skills and experiences which in turn combine with phonological processes to promote reading progress.

Tunmer (1989) has reappraised phonological awareness within the broader context of metalinguistic ability i.e. the child's ability to reflect on the structural features of speech and language. He described three broad categories of metalinguistic ability:

(i) Phoneme and word awareness in which the child actively operates on the subunits of spoken language;

(ii) Syntactic awareness in which he/she assigns structural representations to groups of words within sentences;

(iii) Pragmatic awareness in which the child coordinates those properties which govern the **use** of language.

Tunmer has argued that the reciprocal interaction between the three types of metalinguistic abilities is influential in promoting reading development. The first two (phoneme/word awareness and syntactic awareness) are of special relevance in beginning reading. Tunmer and Nesdale's (1985) study, in which a close association between phoneme segmentation ability and nonword reading was found, adds to the wealth of existing evidence for the importance of phonological awareness to reading. Their scatterplots showed that, although many children performed well on phoneme segmentation and poorly on nonword decoding, no children performed poorly on phoneme segmentation and well on nonword decoding. Thus, explicit phonological awareness appears to be necessary, but not sufficient, for acquiring grapheme-phoneme correspondence rules. Tunmer, Nesdale and Wright (1987), in a reading-age-matched design, demonstrated that good readers are significantly better than poor readers on measures of syntactic awareness e.g. correcting grammatical errors within sentences.

Tunmer (1989) has suggested that syntactic awareness might influence reading ability in the following ways. First, children may use syntactic knowledge to help them monitor their ongoing comprehension processes more effectively; this enables them to check on the meanings of words they encounter by reference to the surrounding grammatical context, and to make intelligent and informed guesses about word meanings. The second way syntactic awareness might influence reading development is through facilitating phonological recoding skills. Beginning readers often combine incomplete phonological knowledge with content cues in reading material in order to identify unfamiliar words.

Also, children with good syntactic awareness may try out different pronunciations of words in which a single letter sequence is associated with more than one pronunciation; so they come to learn about complex relationships between orthographic patterns and pronunciations. Finally, the ability to use grammatical context may help young readers to learn about exception words.

Tunmer (1989) in a longitudinal study provided evidence to support the claim that both syntactic and phonological awareness are essential for acquiring knowledge of grapheme-to-phoneme correspondences. He administered tests of verbal ability, concrete objectivity, phonological and syntactic awareness, and reading to 100 six-year-old children at the end of first grade and again one year later. Path Analyses demonstrated that **both** phonological and syntactic awareness influenced reading comprehension through phonological recoding (as measured by a nonword reading test). There were no children who scored well on the nonword reading test but did poorly on the phonological or syntactic awareness tests. In turn, concrete objectivity (a Piagetian-based test and concept) independently influenced both syntactic and phonological awareness. This latter finding supports Tunmer's theory that metalinguistic abilities are linked to the Piagetian process of decentration i.e. in this context, the ability to shift one's attention from message content to the properties of language conveying the content. Decentering is a central concept in the first stage of Marsh, Friedman, Welch and Desberg's model of reading development discussed at the beginning of this chapter. Tunmer goes on to explain reading failure in terms of metalinguistic deficiencies arising from a lag in decentering ability (Tunmer, 1989).

Adams (1990) has reviewed research demonstrating that preschoolers' knowledge of letter names is a powerful predictor of later reading success. In some studies, letter name knowledge accounted for a larger percentage of variance in reading ability than phonological awareness or IQ (Chall, 1967). In other studies, it exerted a powerful effect on reading over a subsequent two- to three-year period (Vellutino and Scanlon, 1987; Blatchford, Burke, Farquhar, and Plewis, 1987). One explanation for this significant and persistent influence is offered by Adams (1990). She has suggested that children who recognise most letters by name find it easier to learn about letter sounds. The fact that, in general, the names of the letters are quite closely related to their sounds provides a mediating route through which the child's ability to remember the sounds is hastened. However, while letter naming knowledge is undoubtedly a powerful predictor of subsequent reading success, there is good evidence to show that training in letter names does not give children any appreciable reading advantage (Adams, 1990). A possible resolution of this incongruity is offered in Ehri's (1987) model of reading development. Her semi-phonetic stage is characterised by children's use of alphabet knowledge to create partial (invented) spellings of words. It is at the next stage, after they have mastered phoneme segmentation skills, that they are able to produce phonetically complete spellings. Thus, the model argues for a **combining** of letter naming knowledge and phonological awareness to propel the beginning reader into the fully phonetic stage of reading. Of relevance is the finding of Stuart and Coltheart (1988) that preschoolers' phonological awareness measures significantly predicted reading levels one year later only when combined with their letter-sound knowledge scores. These authors argue that letter knowledge is needed to implement existing phonological awareness skills so that they can go on to influence subsequent reading development. It is, therefore, not surprising that, while more rudimentary phonological awareness skills (e.g. syllable segmentation) can be readily demonstrated in prereaders, other more sophisticated phonological skills (e.g. phoneme segmentation) must await the child learning his/her alphabetic letters before they emerge to effect further reading progress. Additional evidence for a facilitative relationship between phonological awareness and letter-sound knowledge comes from recent training studies, to be discussed at length in Section 1.4.4.

Children learn to speak and to read within familial, social and schooling contexts. It would, therefore, be surprising if environmental factors did not play a part in influencing children's phonological awareness and reading development. Raz and Bryant (1990) confirmed the results of earlier studies that have demonstrated that middle class children make better progress in acquiring early reading skills than do socially disadvantaged children. This superiority could not be attributed to differences in IQ which the authors took great care to control. Their middle class sample was also more skilled on phonological awareness tests (of phoneme segmentation and rhyming). The difference in the two groups' reading levels could be attributed largely to variations in the children's phonological scores. Thus much of the difficulty that disadvantaged children have when learning to read can be traced back to relatively slow phonological development. Raz and Bryant suggest that training in phonological sensitivity may help to compensate for adverse environmental factors.

1.4.4 Training Phonological Awareness

The research reviewed so far has argued for a causal (and interactive) relationship between phonological awareness and early reading. Evidence from correlational studies is limited because it can demonstrate only that a relationship exists; it is not possible to tease out the direction of influence. Longitudinal research can establish a relationship and its direction, but not necessarily that it is causal; both variables could be affected by some unknown, unmeasured other factor (Bryant and Goswami, 1987). A third method of looking at the relationship between two variables, which is able to establish causation, is the training study. However, one source of difficulty with this technique is that it is frequently accused of being artificial (Bradley and Bryant, 1985). In order to establish an unequivocal link between the teaching method under study (in this case, phonological awareness) and its outcome (usually reading), most researchers have felt it necessary to isolate the training method from its customary broader teaching context. Consequently, the ability of training studies to reflect real-life learning is called into question.

Bryant and Goswami (1987) pointed out that most of the earlier phonological awareness training studies failed to fulfil three essential requirements:
(i) the necessity for adequate control groups to rule out the influence of additional factors that are not part of the original hypothesis;
(ii) the need for a sharp separation between the independent variable, phonological awareness, and the dependent or outcome variable, reading - in other words, the training in phonological awareness must not involve reading directly;
(iii) finally, outcome measures must be genuine tests of reading, not just nonwords (though these may be included), but also word reading.

Bryant and Goswami went on to review a range of training studies that either had substantial design problems e.g. unseen control groups, inadequate post-tests, or that failed to produce statistically significant results. The two most influential large scale training studies published prior to the comprehensive Bryant and Goswami review were those of Bradley and Bryant (1983) and Olofsson and Lundberg (1985). In the latter study, 95 rising seven-year-olds were given training in rhyming, segmenting and blending, while the control groups were subjected to either a "non-verbal auditory training programme" or to "normal Swedish preschool experiences". A year later, 83 of these children were given tests of silent reading, reading irregular words and spelling. The results were not as conclusive as had been hoped; the only reliable improvement was recorded for spelling. A follow-up of the children a year later showed no lasting effects on reading and spelling, though there were some qualitative differences between the experimental and control groups (the experimental group made more phonic-based errors than did the control groups).

Bradley and Bryant (1983) conducted a training study with 65 six-year-olds who were poor at sound categorisation. They found that sound categorisation training on its own produced no significant improvements over a semantic training control condition. However, when sound categorisation training was combined with experience of (plastic) alphabetic letters, this did lead to significant improvements in reading and spelling. Consequently, neither of these well controlled and large scale studies established an unequivocal link between phonological awareness training and subsequent improvements in literacy development.

Wagner and Torgesen (1987) suggested three possible reasons why the training studies had, to this stage, produced disappointing results. First, neither of the above studies had begun training the children until they were six. It is highly likely that phonological awareness skills make their biggest contribution to reading development at the very earliest stages of beginning reading, and that consequently the children in Olofsson and Lundberg's and Bradley and Bryant's studies were too old. Second, there was no direct assessment of whether the training affected the targeted phonological skills, as well as subsequent reading ability. Finally, phonological abilities may be very difficult to train directly and in isolation from other components of a literacy programme. Yet Bryant and Goswami (1987) insist that the separateness of the phonological training from the reading experience is crucial to establishing an unequivocal causal link between improvements in phonological awareness and later gains in reading. More recent studies (see below) have demonstrated that, with appropriate experimental design features, the relationship between phonological training and subsequent reading development can be clarified without the necessity of separating the two constituent processes.

Training studies conducted during the last five years have overcome some of the reservations expressed by Wagner and Torgesen, and have taken us several steps forward in our understanding of the connection between phonological awareness development and progress in reading. Lundberg, Frost and Petersen (1988) established that their sample of 235 six-year-old kindergartners were true prereaders (only one child could read any words at all at pre-test); consequently, they did seem to be at the very earliest stage of literacy development for which phonological awareness training might be of direct relevance. Second, as well as evaluating the effects of extensive (eight months) sound sensitivity training on reading and spelling development, they also looked at the children's performance on a wide range of phonological awareness measures (given at post- as well as pre-test). The training improved phonological awareness at post-test, especially phonological manipulation; this effect was specific because the training had no effect on letter knowledge or verbal comprehension. Phonological awareness training also improved reading, and more particularly spelling, but not arithmetic, in Grades 1 and 2. It should, however, be pointed out that the authors define the statistical significance of the Grade 1 improvement as "only marginal" ($p < .10$).

Three recent training studies have demonstrated that it may not be viable to separate phonological awareness training from within the context of reading instruction if one is to produce meaningful improvements in children's performance on literacy tasks. The first of these studies, by Ball and Blackman (1988), looked at the effects of training on 151 five-year-olds over a seven-week period. The children were allocated to one of three groups. A phoneme awareness group received instruction in word segmentation, letter names and sounds, and sound categorisation. The language activities group was subjected to general language enhancement exercises, together with the learning of letter names and sounds. A control group received conventional classroom instruction. The children were pre- and post-tested on a range of educational measures and on a test of phoneme segmentation. At post-test, the phoneme awareness group performed at a significantly higher level than the other two groups on the test of phoneme segmentation. These children also achieved significantly higher reading scores than those in the other two groups. The authors conclude "the most pedagogically sound method of phoneme awareness training is one that eventually makes explicit the complete letter-to-sound mappings in segmented words" (p. 64).

A similar observation was made by Cunningham (1990) in her training study of kindergarten and first grade children allocated either to a phonics "skill and drill" group, a "metalevel" group in which phoneme awareness training and reading were explicitly and actively linked, or a "listening to stories" control group. Both experimental groups were better than the controls on phonemic awareness tests given after 10 weeks training. They also scored higher on the test of reading given at post-test. However, the improvements were significantly greater for those children having metalevel instruction than for those experiencing skill and drill training.

Hatcher, Hulme and Ellis (in press, 1994) have pointed out that the results of training studies conducted over the last 10 years have failed to demonstrate a straightforward causal relationship between phonological awareness and subsequent improvements in reading. Rather, the available evidence supports an alternative view that they term the "phonological linkage" hypothesis. According to this hypothesis, training in phonological skill that is isolated from reading and spelling may be less effective than training that forms explicit links between children's underlying phonological skill and their experiences in learning to read. They were able to test this hypothesis by carrying out a training study in which 128 poor readers aged seven years were allocated to one of four groups matched on age, IQ, and reading age. The reading + phonology group received phonological awareness training, reading experience and activities that linked the two components. The phonology alone group experienced the same phonological training given to the reading + phonology group, but had no explicit reading instruction or phonology linkage exercises. The reading alone group read books, had multisensory training and learned letter names (but had no phonological training). A control group received conventional classroom instruction. After pre-testing on cognitive, phonological awareness and educational measures, the children were subjected to 40 sessions of individual instruction over a 20 week period. At post-test, the reading + phonology group scored significantly higher than the other groups on measures of reading; these improvements were sustained at follow-up nine months later (at least for the reading comprehension measure). This effect was specific to reading; there were no differences between the groups on their arithmetic scores. The beneficial effects of the reading + phonology intervention were not purely mediated by changes in phonological skill. Larger improvements in phonological skills at post-test were obtained for the phonology alone group than for the reading + phonology group without an equal improvement in literacy skill.

Finally, experimental training studies have added weight to the view that phonological processes influence reading through their interaction with other reading relevant skills. Tunmer and Hoover (1992) described a training study in which 98 pre-reading children were assigned to the following four groups, according to their scores on a letter name test and a phonemic segmentation test (the groups were roughly equated on Verbal IQ): low phonological awareness + low letter name knowledge; low phonological awareness + high letter name knowledge; high phonological awareness + low letter name knowledge; and high phonological awareness + high letter name knowledge. The children then went on to receive four training sessions in which they were taught simple grapheme-phoneme correspondences. In a word recognition post-test of the generalisation of the correspondence rules, the high phonological awareness + high letter name knowledge group performed significantly better than any other. Thus, phonological awareness and letter name knowledge have a positive interactive effect on the learning of grapheme-phoneme relationships.

A similar conclusion was drawn by Byrne and Fielding-Barnsley (1989) who studied the acquisition of the alphabetic principle in pre-literate children aged three to five years. They defined this principle as "a useable knowledge of the fact that phonemes can be represented by letters, such that whenever a particular phoneme occurs in a word, and in whatever position, it can be represented by the same letter" (p. 313). The children were first taught how to read the words "mat" and "sat"; they were then asked to decide whether the printed word "mow" should be pronounced as "mow" or "sow". Reliable performance on this transfer task was achieved only by those children who could phonemically segment the speech items, who identified the initial sound segments and who had learned the graphic symbols for the sounds "m" and "s". Thus, phoneme awareness and grapheme-phoneme knowledge are needed in combination for successful acquisition of the alphabetic principle. It is this combined knowledge that enables the child to proceed from the logographic to the alphabetic stage in reading acquisition. Byrne (1992) introduces the concept of "default option" to explain his findings and to accommodate the observation of Stuart and Coltheart (1988) i.e. that some children by-pass the logographic stage and go straight from pre-reading into the alphabetic stage. Byrne claims that if the child's usable knowledge about speech structure does not include the phonemic principle, he or she will read logographically at first (the default option). However, this stage can be circumvented if the child has access to a mental representation of speech at the level of the phoneme and knows how letters symbolise phonemes.

1.4.5 Phonological Processes and Difficulties in Learning to Read

A further way of looking at the ingredients of the beginning reading process is to study the deficiencies of children who have difficulty in learning to read. What they lack can tell us a lot about the skills that are necessary to the reading process. Dyslexic children have invited particular attention because they are known to have specific problems in acquiring early literacy skills, but in other respects their cognitive development is normal. For a comprehensive discussion of definitions of dyslexia, its educational and clinical presentation, and relevant cognitive research within a developmental perspective, see Snowling (1987).

Stage models of reading have characterised most dyslexic children as "arrested" in the first i.e. logographic stage of reading development (Frith, 1985, Ehri, 1987). Such children fail to develop the necessary phoneme segmentation skills that would enable them to crack the alphabetic code. Within a dual-route framework, dyslexic children are usually conceptualised as having problems with the functioning of the non-lexical i.e. indirect route of access to reading and spelling, while their direct access route is unaffected (Jorm, 1983). Group studies of dyslexic children have pointed to deficiencies in phonological awareness. Bradley and Bryant (1978) showed that poor readers were significantly worse than reading-age-matched controls on their oddity test. Snowling, Stackhouse and Rack (1986), in their study of seven dyslexics reading at either the seven or 10 year level, found that all the children were inferior to reading-age-matched controls on tests of rhyming and phoneme segmentation. Rohl and Tunmer (1988) demonstrated that children who are poor spellers find it harder to tap out phonemes than do younger children having a comparable spelling age. Finally, Bruck and Treiman (1990) showed that 10-year-olds with a reading age of only seven years had greater difficulty on a phoneme deletion test than did normal seven-year-olds. In relation to the reading process itself, dyslexic children have been found to have much greater difficulty in reading unfamiliar words and nonwords than do younger children having a similar reading level (Frith and Snowling, 1983, and Snowling et al., 1986). The research into the specific deficiencies shown by dyslexic children adds weight to the argument that phonological skills, through their influence on the use of alphabetic strategies, are crucial to successful early reading. If these skills are lacking, or their development disrupted, severe reading backwardness may result.

Group studies of dyslexic children have been complemented by single case studies that allow a detailed appraisal of the deficits affecting particular children and their capacity to compensate for them. It may be the overlay of compensation processes on an existing deficit that accounts for the individual variations seen in dyslexic (and to a lesser extent, normal) children as they proceed through the early stages of learning to read.

A number of single cases of developmental phonological dyslexia have been reported in the literature; amongst those most extensively studied are RE (Campbell and Butterworth, 1985), HM (Temple and Marshall, 1983) and JM (Hulme and Snowling, 1992). In

Frith's model, these individuals would be conceptualised as arrested in the logographic stage. RE was a dyslexic undergraduate who had an extensive vocabulary of word-specific spellings; however, her spelling errors were markedly non-phonological and she had great difficulty in spelling nonwords. HM was a 17-year-old girl with a reading age of 10 years. Her reading skills were characterised by her finding regular words no easier to read than irregular words. She also had great difficulty in reading nonwords. Hulme and Snowling's 13-year-old JM appeared to have problems of output phonology. He performed at a lower level than reading-age-matched 10-year-olds on tests of nonword repetition, yet he had no difficulty in discriminating the same nonwords. Hulme and Snowling were able to demonstrate experimentally that JM had managed to achieve his reading level of 10 years through reliance on visual processes in reading, and on semantic and context cues in continuous reading.

A smaller number of cases of developmental surface dyslexia have been reported. Surface dyslexics typically demonstrate an overreliance on letter-sound rules, which means that they have no difficulty in reading regular words and nonwords, but they do tend to regularise irregular words e.g. reading "broad" as "brode" and "great" as "greet" (Temple, 1985). Thus, in Frith's terms, surface dyslexics would be arrested in the alphabetic stage. Temple (1984, 1986) compared and contrasted the reading and writing characteristics of two bright and verbal 10-year-olds: AH, a developmental phonological dyslexic, and RB, a developmental surface dyslexic. Both children were reading at the eight year level. AH displayed the typical pattern of a phonological dyslexic in that he had difficulty reading and spelling nonwords, he made phonologically invalid spelling errors, and he showed a tendency towards paralexic reading errors. RB, on the other hand, had good nonword reading and spelling, made phonologically valid spelling errors, and most of her reading errors were neologisms. RB also proved more proficient at reading and spelling regular than irregular words, while for AH there was no difference. AH performed poorly on tasks of rhyme recognition and fluency, while RB had no difficulty with these tasks. Thus, developmental dyslexics, even of the same age, ability and reading level, may display qualitatively different patterns of reading and spelling performance indicative of different types of developmental dyslexia.

Individual differences in dyslexics might be conceptualised as arising from their strengths and weaknesses in those cognitive processes essential to reading, together with their capacity (and opportunity) for developing compensatory mechanisms. Rack, Snowling and Olson (1992) have proposed that, in the absence of firm evidence favouring discrete and separate dyslexic subtypes, it may be more appropriate to conceive of an individual child as positioned on a dimension ranging from phonological dyslexics to surface dyslexics. Temple (1985) has also suggested that a dimensional model better fits the available data. In relation to surface dyslexia, she has suggested that this term be used to describe a group of disorders, in preference to attempting subclassifications. Thus, surface dyslexia may be ranked quantitatively, in terms of overall severity of disorder of the phonological route (which is not infrequently impaired in surface dyslexics), and qualitatively in terms of the particular reading subsystems involved. The performance of each subsystem may also be assessed quantitatively. Thus, a number of dimensions is produced across which surface dyslexias may vary; this then accounts for the varying types and proportions of errors surface dyslexics might display.

Finally, it is possible to accommodate individual differences in reading progress and disabilities like dyslexia within a connectionist framework. Seidenberg (1992) suggests that reading failure might derive from impairments in different components of the system and from different types of impairments within the components. For instance, a reduction in the number of hidden units would mean that the computational model was under-resourced. Seidenberg and McClelland (1989) compared a normal model of 200 hidden units with a dyslexic simulated model of only 100 units. The latter model was still able to learn, but it performed poorly on irregular words and nonwords (like many "real" dyslexics in fact). Another possibility is that the phonological representations could be damaged, fail to develop normally, or there may be an impairment in the ability to activate them. Although the necessary simulation has not yet been performed, Seidenberg (1992) has predicted that "coarsening" the phonological representations in the model would increase the confusability of phonemes and consequently impair the encoding of spelling-to-sound correspondences.

1.5 Working Memory and Beginning Reading

Learning to read obviously depends upon memory processes. The role of working memory (particularly phonological working memory) has been strongly implicated in both normal reading development, and as a contributory cause of reading failure. Working memory refers to a set of systems responsible for the temporary storage of information during the performance of cognitive tasks. The most widely accepted model of working memory is that formulated by Baddeley and Hitch (1974). They have conceptualised working memory as a complex of stores and systems within which information is processed during the performance of a cognitive task. It consists of a limited capacity central executive interacting with two slave sub-systems; the speech-based articulatory loop and the visual image scratch pad. It is the articulatory loop which plays a crucial part in ongoing reading processes. The central executive controls the manipulation and flow of information, retrieves relevant information from other parts of the memory system, and forms associations and relationships between items in memory. Only a small amount of information can be retained in the articulatory loop, the maintenance of which is dependent on rehearsal. The functioning of the articulatory loop is seen as crucial to the performance of conventional short-term memory tasks such as span tests.

There is substantial evidence for a close relationship between short-term memory functioning and reading development. Hulme (1988) assessed memory span (for words of differing lengths), and the reading comprehension of children aged from seven to 10 years. The correlations between memory span and reading comprehension were significant, even after partialling out the effects of age, IQ and language comprehension. Additional evidence comes from Bradley and Bryant (1983), and from Wagner and Torgesen's reworking of the Liberman and Mann (1984) and Mann (1984) data. Using step-wise regression procedures for the analysis of longitudinal data, these authors have been able to demonstrate that phonological awareness and memory measures make separate and independent contributions to later reading development. Further support for a link between memory functioning and reading ability comes from studies of dyslexic children who are frequently shown to perform poorly on tests of short-term memory e.g. digit span measures (Jorm, 1983). The short-term memory deficits in poor readers are specific to test materials that lend themselves to verbal i.e. phonological encoding (Wagner and Torgesen, 1987). When the stimulus material is non-phonetic e.g. nonsense shapes or unfamiliar faces, poor readers are not disadvantaged (Katz, Shankweiler and Liberman, 1981). Snowling and Hulme (1989) found that their severely dyslexic boy, JM, at age 12, had the word memory span of an average five-year-old, but he had no difficulty in remembering abstract shapes.

A further line of research, adopting longitudinal and experimental paradigms, has been pursued by Gathercole and Baddeley (1989). They have argued that the phonological memory system contributes to vocabulary development and the acquisition of reading skills. In a two-year longitudinal study of over 100 four-year-old children, they demonstrated that performance on a test of nonword repetition (their measure of phonological memory) predicted the children's receptive vocabulary scores one year later, after controlling for the effects of age and non-verbal intelligence. Gathercole and Baddeley (1990) went on to conduct an experimental study comparing ease of vocabulary acquisition in five-year-old children judged to have either good or poor phonological memory skills (as measured by their nonword repetition scores). The two resultant groups were matched for non-verbal IQ, after which the children were required to learn real and nonsense names for four unfamiliar toys. The low memory group took longer to learn the nonsense names than did the high memory group, leading the authors to conclude that phonological memory skills contribute to the acquisition of new vocabulary.

The link between phonological memory and reading development has been studied by Gathercole, Baddeley and Willis (1991). They conducted a three-year longitudinal study of children, originally selected as prereaders, and looked at the changes in the contribution of phonological memory to reading achievement over time. Their data suggested that phonological memory skills were not particularly important to the child's success in mastering the earliest stages of reading, but played a strong role in the second year of learning to read. By the third year, this specific link between phonological memory and reading had substantially reduced. Gathercole et al. postulate that phonological memory makes its greatest contribution to reading as the child enters the alphabetic stage of reading development. Nonword repetition difficulties have been demonstrated in known dyslexic children (Snowling, 1981; Snowling, Goulandris, Bowlby and Howell, 1986; Taylor, Lean and Schwartz, 1989).

Snowling and her colleagues have challenged the assumption made by Gathercole and Baddeley that a test of nonword repetition is a pure and direct measure of "phonological memory". Snowling, Chiat and Hulme (1991) have argued that nonword repetition tests assess, not only memory processes, but also phonological segmentation and possibly assembly of articulatory instructions. They showed that there is not a systematic increase in repetition difficulty as length of the nonword increases, a finding which is inconsistent with a memory interpretation of the test. The ease of repetition of a given nonword may be as strongly related to its morphemic and phonological similarity to real words as it is to its length. Snowling et al. further point out that even the effects of length of the nonword cannot simply be attributed to the influence of memory. Longer items are not only harder to remember, but they also place greater demands upon other phonological processes such as segmentation and the assembly of articulatory motor programmes. Relevant to this and to other research into memory and reading is the point made by Hulme and Mackenzie (1992), to the effect that it may be very difficult to separate phonological storage mechanisms from other phonological processes. It is clear that many phonological awareness measures contain a sizeable working memory component (e.g. Bradley's oddity test), while measures of phonological working memory are often simultaneously tapping other phonological processes (e.g. nonword repetition tests). To what extent phonological skills and working memory processes are inextricably linked and to what extent they function independently is an issue in need of further research.

Some models of reading development have made explicit reference to working memory processes as an integrated component within a phonologically based framework of reading development. The model described by Shankweiler and Crain has been developed during the 1980s, with their most up-to-date version described in a series of recent papers (Shankweiler, 1989, Crain, 1989, Shankweiler, Crain, Brady and Macaruso, 1992). Their conception of memory processes and reading draws on a model of working memory that is not identical to that of Baddeley and Hitch (1974). The latter is a general information processing system, while Shankweiler and Crain's verbal working memory is a specialised device that specifically serves the language apparatus. Working memory has both storage and control functions. The storage buffer is a limited capacity store where the rehearsal and analysis of phonetically-coded material takes place. The primary function of the control component is to regulate the flow of linguistic information through the system. One of its jobs is to transfer phonologically analysed information out of the limited memory store and push it upwards to a syntactic processor, while at the same time freeing the storage area to accept the next chunk of phonological material. The phonetic information must be analysed and decoded at an optimal rate if the working memory system is to function efficiently. Excessively slow phonetic decoding, that one would expect to observe in dyslexic children, constricts the working memory system. A deficit in the processing of the phonetic information within the storage buffer results in a bottleneck that impedes transfer of information to higher levels in the system. The problem here is not one of limited buffer capacity, but rather one of inefficient transfer of phonological information up to the higher components of the verbal working memory system during on-line processing. Consequently, access to syntactic, semantic and pragmatic structures higher up the system is severely compromised.

Consistent with this conceptualisation of phonological working memory and reading, McDougall, Hulme, Ellis and Monk (in press, 1994) have demonstrated that differences in reading ability are associated with differences in the efficiency of the speech based rehearsal component of short-term memory span. Children's scores on a test of speech rate made a significant contribution to reading skill independent of that made by two measures of phonological awareness.

Shankweiler and Crain go on to explain how phonological processing difficulties, through their impact on working memory, are responsible for poor readers' failure in reading comprehension and in the understanding of semantically or grammatically complex sentences. They argue that the observation of semantic difficulties in dyslexics (see Section 1.4.3 of this chapter) arises because of the heavy memory demands of many comprehension tasks. They have shown that, by adopting procedures that minimise processing requirements, children with reading disabilities are able to perform as well as good readers on a wide range of sentence comprehension tasks. This model offers a different perspective on semantic processing and reading than that described by Tunmer (1989). Tunmer has himself acknowledged that the results of his studies are not inconsistent with an interpretation in terms of the use of phonological structures within working memory.

1.6 Visual Processes in Beginning Reading

As will be clear from the previous discussion, recent research has emphasised the role played by language, especially phonological, factors in early literacy development, with visual processes receiving comparatively little attention. However, it is evident, within the developmental stage models and the dual-route perspective, that there are other, non-phonological, factors that influence early reading and spelling level. The initial (logographic) stage in most developmental models highlight visual processes as being paramount for the majority of children, at least in relation to reading. The direct access route in the dual-route model is one which supposedly operates according to non-phonological principles.

In the more recent, modified versions of the dual-route model, the direct access route for reading irregular and familiar words is one which is viewed as not necessarily purely visual. In Ehri's 1992 model of sight reading development (see Section 1.2), specific connections between visual cues (letter sequences) in a word and its pronunciation are stored in memory. These connections are made possible, and continue to be facilitated, through the child's knowledge of the sound-to-letter relationships that were used to initially learn the word. Thus, the orthographic lexicon is established, maintained, and accessed through interactions (or connections) between phonological and visual properties of words.

There is good reason to believe that visual and phonological routes are used differentially in the very early stages of reading and spelling development. Evidence for predominantly visual processes operating in beginning reading comes, first from a series of studies carried out by Bryant and his colleagues in the 1980s. Bryant and Bradley (1983) showed that concurrent vocalisation, that would be expected to disrupt phonological processing, had no effect on whole word reading in six- and seven-year-old children. Kimura and Bryant (1983) demonstrated that visual confusability interfered with children's reading performance on a picture-word matching task, while concurrent vocalisation did not. More recently, Johnston, Anderson, and Duncan (1991) have found that the reading accuracy of seven-year-olds is enhanced for words having salient graphic features ("risers" and "descenders" e.g. plate, as opposed to "flat" words e.g. case). This differential effect is, however, not evident in older readers i.e. 10-year-olds.

In spelling, children appear to by-pass a logographic stage, and use phonological processes right from the beginning. Young children's attention to, and use of, letter-to-sound relationships is evident in their invented spellings (Read, 1986). Bryant and Bradley (1983) showed that, in contrast to their findings for reading, concurrent vocalisation resulted in lower spelling accuracy than when the children wrote spellings while silent. A double dissociation effect in reading and spelling can be demonstrated if one looks at children's reading and spelling of the same words. Bryant and Bradley (1980) asked children of low reading age (seven years) to read and spell the same list of words on two separate occasions. They were particularly interested in the words children could read but not spell, and more importantly the words they could spell but not read. Words that were read but not spelled were typically ones that did not lend themselves to phonemic codes e.g. "school, light", while words that were spelled correctly but not read tended to be readily phonemically coded e.g. "bun, mat". Children can be pushed into reading the latter words by priming them with a nonword reading task which of course encourages the use of a phonemic strategy.

One reason for the lack of attention given to visual processes in beginning reading has been the move away from visual to phonological causes of reading difficulties in the learning disabilities and dyslexia literature. Since Vellutino (1979) launched what was viewed as a final and definitive attack on visual processing deficits as being the cause of reading failure, the pendulum has swung completely towards an emphasis on language and phonological deficiencies in dyslexic youngsters. However, there has been a recent resurgence of interest in visual aspects of reading and reading failure. Stanovich (1992) cites three reasons for a visual revival:

(i) It is possible that visual deficits may affect a small subgroup of dyslexic children - data demonstrating visual deficits in this subgroup may get swamped in samples containing children with mostly phonological deficits;

(ii) The apparent inability to find visual problems in many studies of dyslexics could be accounted for by developmental changes i.e. visual deficits may characterise failure only in the early stages of learning to read (presumably, the logographic stage);

(iii) Recent research, using sophisticated psychophysical techniques, claims to have uncovered subtle visual problems in dyslexic children, demonstrable only when a stimulus is very briefly exposed.

Lovegrove (1991) claims that 75 percent of dyslexic children have a relative impairment in their transient system i.e. the component within the visual system that signals the timing of visual events, and which is sensitive to rapidly moving stimuli. Flicker fusion frequency, at the spatial frequencies characteristic of the transient system, is found to be lower in dyslexics than normals. Lovegrove has suggested that a deficient transient system means that dyslexics cannot integrate peripheral and central visual information across fixations during reading.

Stein and Fowler (1982) agree with Lovegrove that the transient system of dyslexic children fails to develop normally. They claim that this causes unstable vergence control as the two eyes converge on small near objects. The resultant poor binocular control and stereoacuity leads to mis-sequencing of letters in reading and apparent nonword reading errors (Stein, 1991). These abnormalities of visuomotor integration are said to be detectable as an unfixed reference eye on the Dunlop Test (Dunlop, 1972). Stein and Fowler (1982) found that two-thirds of the dyslexic children in their sample demonstrated unstable binocular control assessed by the Dunlop Test. The same authors went on to show that occlusion of one eye (using patched spectacles) encouraged the development of a reference eye, promoted binocular stability and also improved reading ability (Stein and Fowler, 1985).

The findings of Stein, Fowler and their associates have, however, proved difficult to replicate (Bishop, 1989). Bishop, Jancey and Steel (1979) and Newman, Kerle, Wadsworth, Archer, Hockly and Rogers (1985) found that the Dunlop Test failed to discriminate good from poor readers. Indeed, substantial numbers of normal readers have been found to have an unfixed reference eye (Bishop, 1989). The Stein and Fowler occlusion treatment study has also invited criticism from Bishop (1989). She drew attention to the study's failure to report information on age, IQ and initial reading level, and the possible bias in allocating subjects to occlusion versus placebo spectacle groups. When Bishop reanalysed the original raw data provided by Dr Stein, she found that there were computational inaccuracies. Bishop concluded "When direct comparisons are made between treated and untreated children, differences in amount of reading progress are not significant. There is a significant relationship between development of stable reference and improvement in reading, but this is explicable in terms of differences in initial reading ability. Those children who developed stable reference in the first phase of the study tended to be those whose initial reading problems were less severe" (p. 214).

The findings of the studies conducted by Lovegrove and Stein and Fowler are clearly at odds with the view of dyslexia as being caused by a deficiency in phonological processing. To what extent they are reconcilable is an issue which can only be resolved through further research.

1.7 Conclusion

This chapter has reviewed research on the cognitive determiners of beginning reading, and on the strategies adopted by children as they learn to read. Phonological awareness (alongside letter name knowledge and IQ) is a powerful predictor of early reading development. Recent studies have suggested that children's awareness of different units of sound (e.g. phonemes versus onsets and rimes) might influence different aspects or strategies of early reading (e.g. phonics versus analogy, respectively). This theme is to be explored in the following two chapters.

Chapter 2

A Longitudinal Study of Beginning Reading and Spelling

2.1 Introduction

Bradley and Bryant (1983, 1985) have proposed that studies of the cognitive processes that influence beginning reading should combine two approaches, in essence complementing each other. These are longitudinal studies of skills thought to contribute to early reading development, and experimental studies containing a training component. Neither type of study is in itself sufficient for demonstrating causation as such but in combination they can have the effect of, not just confirming the others' findings, but also of cancelling out each others' methodological disadvantages. Longitudinal studies, while establishing the presence of a relationship and its direction in the real world, cannot unequivocally confirm causation. Experimental training studies, because they manipulate events in a controlled way, can establish causation. However, they can be criticized of artificiality i.e. they do not necessarily mirror what would happen in real life. Since the strengths and weaknesses of the two methods are complementary, they can in combination provide strong evidence for the existence, direction and strength of specific cognitive influences in beginning reading. This chapter describes a longitudinal study of early phonological and literacy development in children aged from four to six years. Chapter 3 describes an experimental study, with a training component, that looks at the processes involved in children's use of analogy in early reading.

Bryant and Goswami (1987) and Wagner and Torgesen (1987), in their review papers, discuss criteria for the guaranteed methodological soundness and the successful implementation of a longitudinal design in the study of early reading development. These may be summarised as follows:

(1) Prediction should take place over a suitably lengthy period of time, preferably not just one year but two;

(2) The effect of the independent variable on the outcome measure must be a specific one e.g. that phonological awareness has a significant influence on reading but not on arithmetic;

(3) It is crucial to control for other possible contributory influences over the outcome measure, so that a separate and independent effect of the variable of interest can be demonstrated. For example, that phonological awareness significantly contributes to reading after controlling for the effects of IQ on reading;

(4) The independent variables under study should be assessed at three (preferably equidistant) points in time;

(5) The subjects selected for the research should not have pre-existing reading skills at the outset of the study;

(6) Since the relationship between the independent variables and the outcome measures may be reciprocal, it is important to look at both directions e.g. the effect of reading on phonological awareness as well as the effect of phonological awareness on reading.

The present longitudinal study (described in Chapters 2 and 3) met the above criteria, and investigated the direction and magnitude of critical cognitive influences over early reading development. The five independent variables under study were: IQ, phonological awareness, letter knowledge, visual memory and verbal short-term memory. Thirty eight children were recruited at age four, as non-readers, and tested at three equidistant points in time over a two year period; at age four, while still at Nursery School, and at ages five and six after they had progressed to Infants School. The outcome measures were standardised tests of reading, spelling and arithmetic.

2.2 The Nature and Development of Phonological Awareness

2.2.1 Introduction

The availability of five different phonological awareness measures created an opportunity for addressing an important theoretical issue. Given the modest sample size, it was deemed necessary to attempt to reduce the number of variables to more manageable proportions for inclusion in Multiple Regression and Path Analyses. At the same time, reducing the number of variables, by means of a Principal Components Analysis, meant that it would be possible to address the issue of whether phonological awareness is a single global entity, or whether there are a number of constituent subskills, each of which might play a different role in early literacy development.

Stanovich, Cunningham and Cramer (1984) gave ten different phonological awareness tests to kindergarten children: rhyme detection and production, detection of same initial and final consonant, phoneme deletion, two tests of detection of different initial consonant, detection of final consonant, supplying of initial consonant, and substitution of initial consonant. They found that the seven non-rhyming phonological tests were highly intercorrelated. It might be argued that Stanovich et al.'s conclusions are weakened by the finding that many of the kindergartners they studied were at ceiling on the rhyming tests. Nonetheless, a Principal Components Analysis revealed only one factor on which all the non-rhyming tests loaded highly. Stanovich et al. reported that these seven measures were all moderately related to later reading ability and, when employed in sets, proved to be very strong predictors. Wagner and Torgesen's (1987) Principal Components Analysis of Lundberg, Olofsson and Wall's 1980 data also yielded just one factor.

In contrast, Yopp (1988) uncovered two factors from a Principal Components Analysis (with oblique rotation) of ten phonological awareness tests given to 96 kindergarten children. The tests of phoneme blending, segmentation, counting and isolation loaded highly on one factor. Phoneme deletion tests loaded highly on a second factor. The two factors were highly related, however, and appeared to reflect two levels of difficulty rather than two qualitatively different kinds of skill. The first factor, *Simple Phonemic Awareness*, required only one cognitive operation, the segmentation, blending or isolation of a given sound followed by a response. The second factor, *Compound Phonemic Awareness*, involved two operations, and placed a heavier burden on memory; the respondent performed an operation, such as isolating a given sound, then held the resulting sound in memory while performing a further operation (phoneme deletion or manipulation). Both factors accounted for a significant proportion of the variance in a nonword reading task. Rhyming ability was only minimally involved in these two factors, which led Yopp to conclude "Rhyme tasks may tap a different underlying ability than other tests of phonemic awareness" (p. 172).

On the basis of these findings, Yopp recommended caution about reading research that draws its conclusions about phonological awareness from rhyming tasks. However, Goswami and Bryant (1990) do not share this view. They have argued that segmentation, deletion and similar tasks are measures of phonemic awareness, while rhyming tests are sensitive, not to individual phonemes within words, but to onset-rime units within words. So tests of phoneme awareness tap the phonemic structure of the word e.g. c-a-t, while tests of rhyming access its onset-rime boundary e.g. c-at. Thus, according to Goswami and Bryant (1990), rhyming and segmentation skills should exert quite different influences over reading and spelling development.

2.2.2 Method

2.2.2.1 Subjects

Thirty eight children were recruited at age four from North London Local Authority Nurseries. They ranged in age from 3 years 10 months to 4 years 9 months, with a mean age of 4 years 3 months (standard deviation = 3.31) . Their mean IQ, based on four Verbal and four Performance subtests of the Wechsler Preschool and Primary Scale of Intelligence (Wechsler, 1963) was 114.16 (s.d. = 10.66, range 90 - 142). The selection of the children was random, with one proviso; they had to be non-readers at the outset of the study. All the children were screened on the British Ability Scales Word Reading Test (Elliott, Murray and Pearson, 1983). Any child reading even one word correctly was excluded from the study.

2.2.2.2 Design and Procedure

All 38 children underwent extensive testing at three equidistant points in time over a two year period. In Year 1 of the study, they were attending local Nursery Schools. In Years 2 and 3, they were attending State Infants Schools. No children were "lost" during the course of the study, so all 38 children supplied complete data for each of the three data collection points. Data were collected during a series of individual sessions, each of approximate duration 20 - 30 minutes during a three- to four-week period, at the children's nurseries or schools.

2.2.2.3 Materials

Year 1 : A shortened version of the Wechsler Preschool and Primary Scale of Intelligence (Wechsler, 1963) was administered to each child. The following subtests were given: Similarities, Vocabulary, Arithmetic, Comprehension, Picture Completion, Block Design, Mazes and Geometric Design.

The following four tests of phonological awareness were administered:
1) Rhyme Detection This test was presented in picture format, with three demonstration items followed by ten test items. The children had to indicate which of three words (e.g. fish, gun, hat) rhymed with or "sounded like" the target word (e.g. cat). All words were accompanied by a representational drawing. The instructions were given as follows: "Here is a picture of a cat. Which of these three, fish, gun or hat (the child named them out loud) rhymes with or sounds like cat?". The test was scored for number of correct rhyming responses out of ten.
2) Rhyme Production In this test, the children were given 30 seconds to produce words which rhymed with each of two target words (day and bell), both real and nonwords being permissible responses. The score was the number of rhyming words produced by the child during the time limit.
3) Phoneme Identification This was based on a test devised by Morag Stuart (Stuart and Coltheart, 1988). The children were shown a series of eight pictures depicting common

objects which had one syllable names. The examiner supplied the first two phonemes of the word which the children were requested to "finish off" with the final phoneme e.g. this is a picture of a "ca-" for which the correct response was "t" to complete the word "cat". Each item was scored 1 or 0.

4) Phoneme Deletion This was based on a test originally devised by Bruce (1964). The children were shown a picture of a common object e.g. a bus, and then requested to say the word after deleting its initial phoneme e.g. "bus without the "b" says --". The correct response was "us", also a word in its own right, and crediting a score of 1. Four demonstration items were given followed by ten test items.

All the words used for the above rhyming and phonological awareness tests were selected from Bridie Raban's corpus of spoken vocabulary in five-year-old British children, and had a minimum frequency rating of five (Raban, 1988).

The stimulus items for the tests of rhyme detection, phoneme identification and phoneme deletion are given in Appendix 2.1.

Two memory tests were administered. The first was one of verbal short-term memory, Digit Span from the Wechsler Intelligence Scale for Children - Revised (Wechsler, 1976). In this test, the children repeated increasingly lengthy digit strings, both forwards and backwards. The second test was a test of Visual Memory for Letter-like Forms (Goulandris, 1989). This consisted of a series of between two and four Greek letters which the children were asked to memorise. They then selected the letters that could be recalled from a larger array and placed them in the same sequence. Half of the twelve items required immediate recall, while the other half had a delayed recall condition of ten seconds during which child and examiner together counted to ten. For each presented array, one point was earned for selecting the correct Greek letters, and an additional point for putting them in the right order.

Finally, a test of Letter Knowledge was given in which the children were asked to name the 26 alphabetic letters written in lower case on individual flashcards and presented in random order.

Year 2 : All the above tests were repeated, with the exception of the Wechsler PreSchool and Primary Scale of Intelligence. An additional test of phonological awareness was introduced i.e. the Sound Blending Test from the Illinois Test of Psycholinguistic Ability (Kirk, McCarthy and Kirk, 1968). In this task, the examiner supplied the constituent phonemes of single syllable words, multisyllabic words and nonwords. The children were asked to "join them together to make the word" e.g. "c - a - t" blends to yield "cat".

The following educational attainment tests were also administered: The British Ability Scales (BAS) Word Reading Test (Elliott, Murray and Pearson, 1983), a test of single word reading, the Neale Analysis of Reading Ability - Revised (Neale, 1989), a test of prose reading, and the Schonell Graded Word Spelling Test (Schonell and Goodacre, 1971), a test of single word spelling.

Year 3 : The same tests given in Year 2 were repeated in Year 3, with the addition of two measures of arithmetical competence. One was the Arithmetic subtest from the Wechsler Intelligence Scale for Children - Revised (Wechsler, 1976), an orally administered test of numerical reasoning. The second test was a curriculum orientated written arithmetic test based on Gillham and Hesse's Basic Number Screening Test (1976); additional items suitable for children as young as five and six were added (see Appendix 2.2).

2.2.3 Results

2.2.3.1 <u>The dependent and independent measures in Years 1-3</u>

The means and standard deviations of all the independent and dependent measures used in the study are given in Table 2.1. These showed a clear developmental progression between ages four and six. In Year 1, rhyme detection turned out to be the easiest task, followed by phoneme identification, then rhyme production, and finally phoneme deletion. The children's scores on all the phonological awareness measures steadily improved during the course of the following two years, though on none of them did the mean score reach "ceiling". In Year 2, the children had only limited literacy skills. The scores on the tests of reading and spelling exhibited a great deal of spread (shown by the large standard deviations), reflecting the considerable variation in the children's literacy levels.

Table 2.1 Means and standard deviations of the independent and dependent measures in Years 1 - 3

	Year 1	Year 2	Year 3
Age	4y3m (3.3)	5y3m (3.3)	6y3m (3.5)
Full Scale IQ	114 (10.7)		
Digit Span (scaled score)	4.00 (1.5)	7.79 (2.5)	9.37 (2.5)
Visual Memory /24	5.74 (2.5)	12.03 (3.3)	17.84 (4.0)
Rhyme Detection /10	5.42 (2.9)	8.11 (2.4)	8.34 (2.5)
Rhyme Production *	1.00 (1.6)	2.71 (3.2)	5.24 (4.4)
Phoneme Identification /8	1.97 (2.5)	3.39 (3.2)	6.32 (2.6)
Phoneme Deletion /10	0.39 (1.4)	2.50 (3.8)	5.18 (4.5)
Sound Blending /32		14.05 (5.4)	18.24 (6.0)
Letter Naming /26	4.26 (6.1)	12.03 (9.5)	18.63 (8.6)
BAS Reading **	0.0	3.84 (5.5)	16.89 (15.0)
Neale Reading **		9.13 (13.2)	57.29 (50.0)
Schonell Spelling **		1.50 (3.7)	7.95 (7.3)
WISC-R Arithmetic (scaled score)			12.79 (2.5)
Written Mathematics /27			15.78 (7.2)

Standard deviations are given in parentheses. Maxima where relevant are indicated as /n. * number of rhyming responses. ** number of words read or spelled correctly.

2.2.3.2 Intercorrelations and Principal Components Analyses of the phonological awareness tests

The scores on the phonological awareness tests were intercorrelated for each year of the study (Table 2.2). Before carrying out these analyses, the distributions of the scores were assessed using histogram analysis (with normal curve superimposed). There was a tendency for some phonological tests to be at floor at age four (rhyme production, phoneme identification and phoneme deletion), while others began to shift in the direction of ceiling effects at ages five and six (rhyme detection). Those scores with roughly normal distributions were retained for raw score analysis. The others with skewed distributions underwent the logarithmic transformation appropriate to their size and direction of skew (Tabachnick and Fidell, 1989). In general, the two rhyming tests correlated highly with each other, but had lower correlations with the remaining tests (phoneme identification, phoneme deletion and sound blending). Conversely, phoneme identification, phoneme deletion and sound blending showed high correlations with each other, but correlated less well with the rhyming tests.

Three separate Principal Components Analyses with Varimax (orthogonal) Rotation were carried out on the phonological awareness tests for each year of the study. In Year 1, two factors were extracted, having Eigen Values of 1.89 and 1.16. The Rotated Factor Matrix showed that the two rhyming measures were heavily loaded on Factor 1, while the phoneme identification and phoneme deletion tests loaded heavily on Factor 2. Factor 1 accounted for 47 percent of the variance, and Factor 2 for 29 percent. A similar pattern emerged in Year 2, though the Eigen Value of Factor 2 did not quite reach 1 (0.97). Factor 1, on which the phoneme identification, phoneme deletion and sound blending tests were heavily loaded, accounted for 50 percent of the variance. Factor 2, on which the rhyming tests were highly loaded, accounted for 19 percent of the variance. In Year 3, the loading pattern was less clear than in the two previous years. Factor 1 accounted for 57 percent of the variance; the rhyming tests loaded very heavily on this Factor, but interestingly, phoneme deletion also exhibited a relatively high correlation with this factor ($r = 0.64$). Factor 2 (which had an Eigen Value of 0.97) accounted for 19 percent of the variance. Phoneme identification and sound blending loaded heavily

Table 2.2. - Intercorrelations of the phonological awareness measures

Year 1

	Rhym Det	Rhym Prod	Ph Id	Ph Del
Rhym Det	1.00	0.63**	0.38*	0.28*
Rhym Prod		1.00	0.19	0.11
Ph Id			1.00	0.32*
Ph Del				1.00

Year 2

	Rhym Det	Rhym Prod	Ph Id	Ph Del	Blnd
Rhym Det	1.00	0.55**	0.29*	0.32*	0.40*
Rhym Prod		1.00	0.12	0.31*	0.36*
Ph Id			1.00	0.44*	0.40*
Ph Del				1.00	0.55**
Blnd					1.00

Year 3

	Rhym Det	Rhym Prod	Ph Id	Ph Del	Blnd
Rhym Det	1.00	0.60**	0.23	0.63**	0.51*
Rhym Prod		1.00	0.15	0.46*	0.49*
Ph Id			1.00	0.41*	0.49**
Ph Del				1.00	0.73**
Blnd					1.00

* significant at .05 level

** significant at .001 level.

Rhym Det - Rhyme Detection   Rhym Prod - Rhyme Production

Ph Id - Phoneme Identification   Ph Del - Phoneme Deletion

Blnd - Sound Blending

on this factor. Phoneme deletion correlated 0.60 with Factor 2. It may be that at least some of the children in Year 3 were treating the phoneme deletion test as a type of "rhyming" game; certainly, the correct response was required to rhyme with the target word (albeit minus the initial phoneme). Thus, in this interpretation, phoneme deletion would be viewed as a test of onset-rime awareness. Other children may have responded to the deletion task as a segmenting game i.e. segmenting the initial phoneme from the remainder of the word. Thus, the two derived factors appeared to be psychologically meaningful, and were termed a Rhyming Factor and a Segmentation Factor, with the factor scores on each retained for future analyses. The loadings of the individual phonological awareness tests on the derived factors, Rhyming and Segmentation, are given in Table 2.3.

Orthogonal rotation of factors, in providing information which is not redundant, offers ease of interpretation, description and reporting (Tabachnik and Fidell, 1989). However, there is the disadvantage that the factors may have been forced to be unrelated, whereas in real life they may be related, thus offering an artificial solution (Bryman and Cramer, 1990). One could argue a case for the underlying processes in phonological awareness tasks being correlated. In order to address this issue, the Principal Components Analyses were repeated for each year, using an oblique (Oblimin) rotation. The Pattern and Factor Correlation Matrices for each year of the study are reported in Table 2.4. The results of the oblique rotation analyses were strikingly similar to those obtained by orthogonal rotation, except that (because the factors were correlated) the loadings between the items and factors were higher. Once again, two factors emerged, having Eigen values of no less than 0.97 in any of the three years. The rhyming tests tended to load highly on one factor, while the phoneme identification, phoneme deletion and sound blending tests loaded more highly on the other. The correlation factor matrices showed that the correlations between the two factors were relatively modest (0.20, 0.35 and 0.33 for Years 1, 2 and 3, respectively), representing about 10 percent overlap in variance. Given that the correlations between the factors were fairly modest, the pattern of loadings on the factors was much the same irrespective of the method of rotation, and the desirability of using factor scores with greater ease of interpretation for subsequent analyses, it was decided to conduct the future analyses using the orthogonal factor solution.

Table 2.3 Orthogonally rotated factor matrices for Years 1 - 3 phonological awareness measures

Year 1

	Factor	
Test:	**Rhyming**	**Segmentation**
Rhyme Detection	0.82	0.32
Rhyme Production	0.91	-0.06
Phoneme Identification	0.20	0.81
Phoneme Deletion	-0.01	0.86

Year 2

	Rhyming	**Segmentation**
Rhyme Detection	0.75	0.29
Rhyme Production	0.90	0.06
Phoneme Identification	-0.01	0.84
Phoneme Deletion	0.26	0.77
Sound Blending	0.40	0.69

Year 3

	Rhyming	**Segmentation**
Rhyme Detection	0.84	0.16
Rhyme Production	0.85	0.07
Phoneme Identification	-0.02	0.91
Sound Blending	0.50	0.72
Phoneme Deletion	0.64	0.60

Table 2.4 Obliquely rotated pattern matrices for Years 1 - 3 phonological awareness measures

__Year 1__

	Factor	
Test:	**Rhyming**	**Segmentation**
Rhyme Detection	0.80	0.24
Rhyme Production	0.93	-0.15
Phoneme Identification	0.12	0.81
Phoneme Deletion	-0.09	0.87

__Year 2__

	Rhyming	**Segmentation**
Rhyme Detection	0.73	0.17
Rhyme Production	0.93	-0.09
Phoneme Identification	-0.18	0.88
Phoneme Deletion	0.11	0.77
Sound Blending	0.28	0.66

__Year 3__

	Rhyming	**Segmentation**
Rhyme Detection	0.86	-0.01
Rhyme Production	0.88	-0.10
Phoneme Identification	-0.16	0.95
Phoneme Deletion	0.58	0.49
Sound Blending	0.42	0.64

2.2.3.3 Correlations of the independent variables with the outcome (educational) measures

The correlations of the Years 1 - 3 phonological awareness factor scores (Rhyming and Segmentation), IQ, visual memory and verbal short-term memory scores with the reading and spelling outcome measures in Years 2 and 3 are given in Table 2.5. Preliminary screening of the literacy data showed that, at age five, the BAS and Neale reading tests and the Schonell spelling test showed a tendency towards positive skew, consistent with floor effects; these scores were consequently subjected to logarithmic transformation before further analysis. It can be seen from Table 2.5 that the Segmentation factor scores in Years 1 and 2 generally correlated far more highly with the reading and spelling scores obtained in years 2 and 3 than did the Rhyming factor scores. Both Rhyming and Segmentation factor scores showed significant concurrent correlations with educational outcome in year 3. IQ and verbal memory in Years 1 and 2 (Digit Span) showed significant correlations (around 0.3 - 0.5) with reading and spelling. The visual memory test generally had low, and non-significant, correlations with the educational outcome measures, except in Year 2 when a significant concurrent correlation (0.49) with spelling was recorded. Letter knowledge correlated moderately highly with reading and spelling (0.4 - 0.7), notably in years 2 and 3 of the study.

Table 2.5 Correlations of the Years 1 - 3 independent variables with Years 2 and 3 outcome (educational) measures

<u>Correlation of Years 1 and 2 independent variables with Year 2 outcome measures</u>

	BAS Reading	Neale Reading	Schonell Spelling
IQ	0.40*	0.29	0.38*
<u>**Year 1**</u>			
Verbal Memory	0.47*	0.50**	0.47*
Visual Memory	0.23	0.26	0.19
Letter Knowledge	0.48*	0.45*	0.26
Rhyming #	0.21	0.15	0.18
Segmentation #	0.21	0.23	0.48*
<u>**Year 2**</u>			
Verbal Memory	0.52**	0.52**	0.38*
Visual Memory	0.37	0.37	0.49**
Letter Knowledge	0.71**	0.73**	0.46*
Rhyming #	-0.08	-0.07	0.13
Segmentation #	0.56*	0.54*	0.64**

* Significant at .05 level.

** Significant at .001 level.

\# Denotes Factor Scores

Table 2.5 (Continued)

Correlations of the Years 1 - 3 independent variables with Year 3 outcome measures

	BAS Reading	Neale Reading	Schonell Spelling
IQ	0.42*	0.42*	0.38*
Year 1			
Verbal Memory	0.43*	0.39*	0.38*
Visual Memory	0.18	0.21	0.39*
Letter Knowledge	0.47**	0.44*	0.43*
Rhyming #	0.06	0.09	0.05
Segmentation #	0.31*	0.26	0.39*
Year 2			
Verbal Memory	0.37*	0.34*	0.40*
Visual Memory	0.36*	0.32*	0.36*
Letter Knowledge	0.69**	0.68**	0.55**
Rhyming #	0.00	-0.05	0.21
Segmentation #	0.60**	0.65**	0.61**
Year 3			
Verbal Memory	0.21	0.17	0.23
Visual Memory	0.0	0.0	0.13
Letter Knowledge	0.62**	0.59**	0.43*
Rhyming #	0.46*	0.48**	0.45*
Segmentation #	0.42*	0.40*	0.63**

2.3 The Relationship between Cognitive Skills, Reading, Spelling and Mathematics Attainments

2.3.1 Introduction

Subsequent to the Principal Components Analyses reported in this chapter, five questions were asked. These addressed issues of theoretical importance in beginning reading and spelling development:

1) What contribution does phonological awareness, in terms of the separate subskills, make to early reading and spelling development?

2) What effect does letter name knowledge have on early literacy development? Is there an interactive effect between letter knowledge and phonological awareness which has a larger, potentiating effect on reading/spelling, above and beyond the additive effect of the individual components?

3) Does visual memory have an influence over early reading and spelling development?

4) Does verbal short-term memory play a significant role in beginning reading and spelling development?

5) Are there reciprocal influences in reading development, specifically of reading and spelling over subsequent phonological awareness, and between reading and spelling themselves?

The method of analysis chosen to address the above questions was that of Path Analysis, an extension of Multiple Regression (Bryman and Cramer, 1990). Series of path diagrams were proposed as models of the relationships between the independent and outcome variables, taking account of existing empirical data and theoretical positions in beginning reading research (see Chapter 1). Path Analysis was used as an exploratoryinductive (rather than confirmatory) procedure (Ellis, 1992). There is no universally agreed causal sequence to developing interactions between variables like reading, phonological awareness and short term memory. Different researchers have produced evidence in support of different directions of causality. For instance, there is evidence that phonological awareness influences subsequent reading development (Adams, 1990), but just as strong a case could be argued for either exposure to print promoting improved phonological awareness (Alegria, Pinot and Morais, 1982), or for a complex reciprocal relationship between these two variables (Bryant and Goswami, 1987). A sample size of 38 children necessarily restricted the scope of the longitudinal study and the scale of the analyses. A series of Path Analyses addressing a number of specific questions and hypotheses, as opposed to one large scale analysis, was proposed. This then made it possible to meet the statistical requirement that there must be at least five times as many subjects as independent variables entered into a single multiple regression analysis (Tabachnick and Fidell, 1989); consequently, for this study no more than seven variables were entered into a single analysis. Furthermore, the analyses should be regarded as preliminary to confirmatory analyses for subsequent data from studies using a larger N (Crano and Mendosa, 1987, Ellis, 1990).

2.3.2 Method

The pattern of relationships between the independent and outcome measures (described in Section 2.2.3) was expressed in the form of a series of path diagrams. These depicted the hypothesised connections between the component variables moving from left to right (Years 1 through 3), implying causal priority to those variables closer to the left. The strength of the relationship along each path was denoted by a standardised path coefficient, computed from a series of multiple regression analyses. Each model, addressing a specific theoretical issue or question, was gradually built up through a cumulative series of Path Analyses, with non-significant paths being "dropped" from the model, while significant paths were retained for re-analysis and further model development. The resultant models were interpreted in the light of existing empirical knowledge, with particular reference to the causal-developmental theory of early reading and spelling proposed by Goswami and Bryant (1990).

The raw scores for each variable were converted into z scores which were then used for all the multiple regression analyses; the purpose of centering the scores in this way was to ensure comparability of measurement scales across all the variables used in the study. Logarithmically transformed scores were not used in the path analyses since this would have required a double transformation of the data. The z score transformation was judged to have greater priority. Also, Tabachnick and Fidell (1989) caution against attempting logarithmic transformation of deviation scores as this can significantly impair the interpretability of the results.

2.3.3 Results

2.3.3.1 What are the relative contributions of rhyming and segmentation skills (factor scores) to reading and spelling during the first two years of school?

The first path diagram (Figure 2.1) depicts the contribution of the Rhyming and Segmentation factors in Years 1 and 2, together with IQ, to the development of Reading (BAS) in Year 2. This diagram was obtained from a series of simultaneous (or standard) multiple regression analyses, working from left to right. IQ and segmentation skills in the nursery year contributed to the children's segmentation ability one year later ($\beta = 0.36$, $p < .05$; $\beta = 0.34$, $p < .05$, respectively). IQ predicted the children's reading skills in the following year ($\beta = 0.34$, $p < .05$), and segmentation ability in Year 2 significantly contributed to reading in that year ($\beta = 0.47$, $p < .01$). Rhyming ability played a non-significant role during the first year of learning to read; rhyming in Year 1 did not contribute to rhyming ability in the following year ($\beta = 0.04$, ns), nor did rhyming skill in Year 2 contribute to reading ability in that year ($\beta = -0.20$, ns).

To see if Segmentation in Year 1 (Segmentation 1) had a direct effect on Reading in Year 2 (Reading 2), a further multiple regression was carried out, entering Segmentation (in Year) 2 ahead of IQ and Segmentation 1 i.e. a hierarchical (or fixed-order) multiple

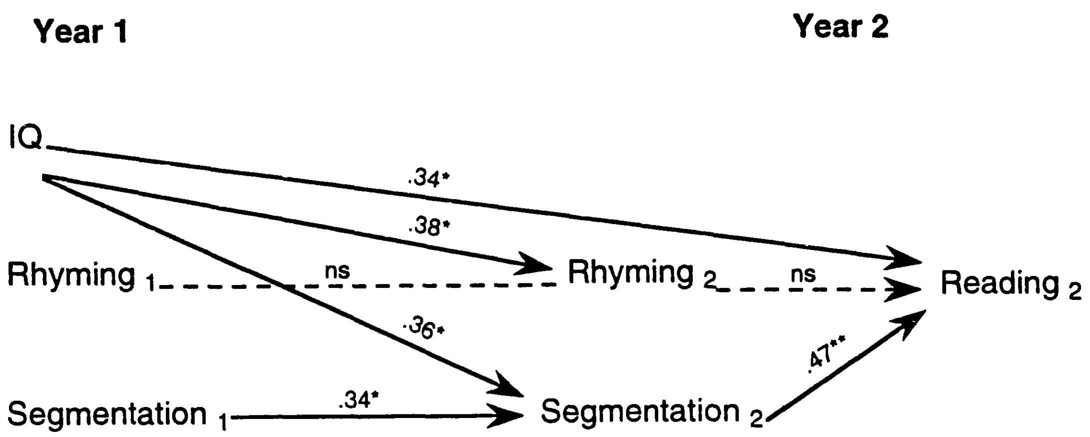

Figure 2.1
Path diagram depicting the contribution of Rhyming, Segmentation and IQ to BAS Reading during the first year of learning to read.

* significant at .05 level
** significant at .01 level
*** significant at .001 level

regression. IQ no longer reached significance (β = 0.26, p = .09), Segmentation 1 made no direct contribution to Reading 2 (β = 0.14, ns), but Segmentation 2's contribution remained highly significant (β = 0.58, p < .001). The multiple regression analysis was then re-run, having removed rhyming as a predictor variable together with the direct path from Segmentation 1 to Reading 2; the resultant path diagram is shown in Figure 2.2.

The above analyses were repeated for the outcome variables, Neale Reading Year 2 and Schonell Spelling Year 2. Again, IQ and rhyming ability failed to make a significant contribution to Neale reading (β = 0.13, ns, for IQ, and β = 0.0, ns, for rhyming), or to Schonell spelling (β = 0.04, ns, for IQ, and β = 0.12, ns, for rhyming). However, the contribution of segmentation in Year 2 remained highly significant (for Neale reading, β = 0.59, p < .001; for Schonell spelling, β = 0.66, p < .001).

It can be concluded that the children's ability to segment words, as demonstrated by the factor on which the phoneme identification and deletion tests had high loadings, was a more important determiner of their reading and spelling abilities during the first year of learning to read than was either IQ or rhyming.

In Year 3, the picture was quite different. Figure 2.3 depicts the model of phonological influences on (both BAS and Neale) reading scores over the three years of the study. While segmentation ability had a profound effect on reading during first year Infants, it failed to continue its contribution into the following year (β = 0.17, ns, for BAS reading, and β = 0.19, ns, for Neale reading). Nor did rhyming ability influence reading development in Year 3 (β = 0.13, ns, for BAS reading, and β = 0.19, ns, for Neale reading). Rather, the only variable that significantly contributed to reading progress in the third year was the children's reading scores of the previous year (β = 0.74, p < .001 for BAS reading, and β = 0.65, p < .001 for Neale reading).

However, in relation to third year spelling, the phonological awareness measures emerged very strongly. Second year rhyming and segmentation skills contributed to their same abilities one year later (β = 0.36, p < .05; β = 0.41, p = .05, respectively). Rhyming

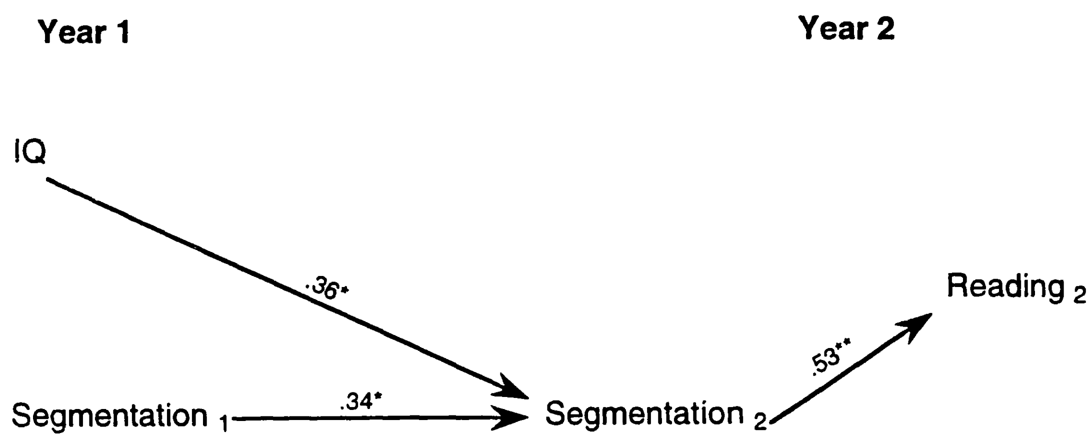

Figure 2.2
Path diagram depicting the contribution of Segmentation and IQ to BAS Reading during the first year of learning to read (after removal of non-significant Rhyming paths).

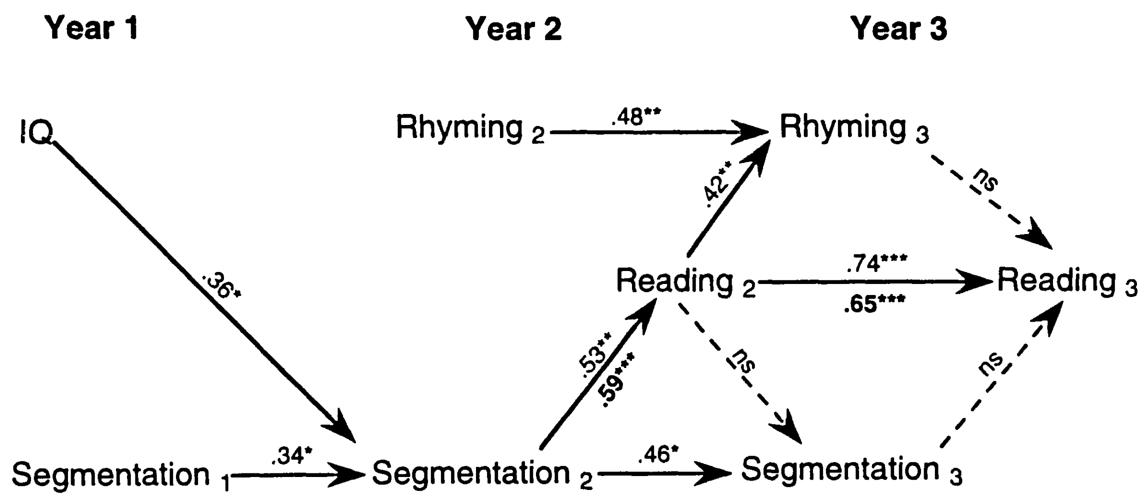

Figure 2.3
Path diagram depicting the relationship between Rhyming, Segmentation, IQ and Reading (BAS and Neale) during the first two years of learning to read.

Bold print indicates Neale Reading.

and segmentation ability in Year 3 went on to significantly contribute to spelling in that year ($\beta = 0.40$, $p < .01$; $\beta = 0.57$, $p < .001$, respectively). The Year 2 phonological scores did not predict year 3 spelling ($\beta = 0.29$, ns, for segmentation, $\beta = 0.0$, ns, for rhyming). Unlike reading, second year spelling did not contribute to spelling ability in the following year ($\beta = 0.16$, ns). The pattern of influence of phonological awareness on spelling during the three years of the study is depicted in Figure 2.4.

In order to demonstrate that the effects of the phonological awareness measures were specific to literacy progress and not to educational ability in general, it was necessary to analyse the contributions of the rhyming and segmentation scores to arithmetical knowledge. Multiple regression analyses demonstrated that neither concurrent rhyming nor segmentation scores significantly contributed to the children's third year scores on the WISC -R Arithmetic subtest, after controlling for the effects of IQ ($\beta = 0.30$, ns, for segmentation, and $\beta = 0.28$, ns, for rhyming). What was (initially) surprising though was that the third year rhyming and segmentation scores made a significant contribution to the children's performance on the written arithmetic test ($\beta = 0.42$, $p < .05$; $\beta = 0.33$, $p < .05$, respectively). However, it could be that the ability to complete a written arithmetic test is dependent on reading skills, since children who read letters and words well presumably also read and interpret numbers and arithmetical operation signs with greater ease than do non-readers. To test out this hypothesis, a further multiple regression analysis was carried out entering the children's BAS reading scores in Year 3 together with the phonological awareness measures. Rhyming and segmentation skills no longer contributed to written arithmetic performance ($\beta = 0.12$, ns, and $\beta = 0.18$, ns, respectively), but BAS reading did so at a significant level ($\beta = 0.52$, $p < .01$).

2.3.3.2 What are the effects of letter name knowledge on early reading and spelling development, and does letter knowledge interact with segmentation skills to potentiate the effects on literacy development?

Figure 2.5 depicts the contribution of Letter (Name) Knowledge and Segmentation to Reading (BAS) during the children's first year of learning to read. Both Letter

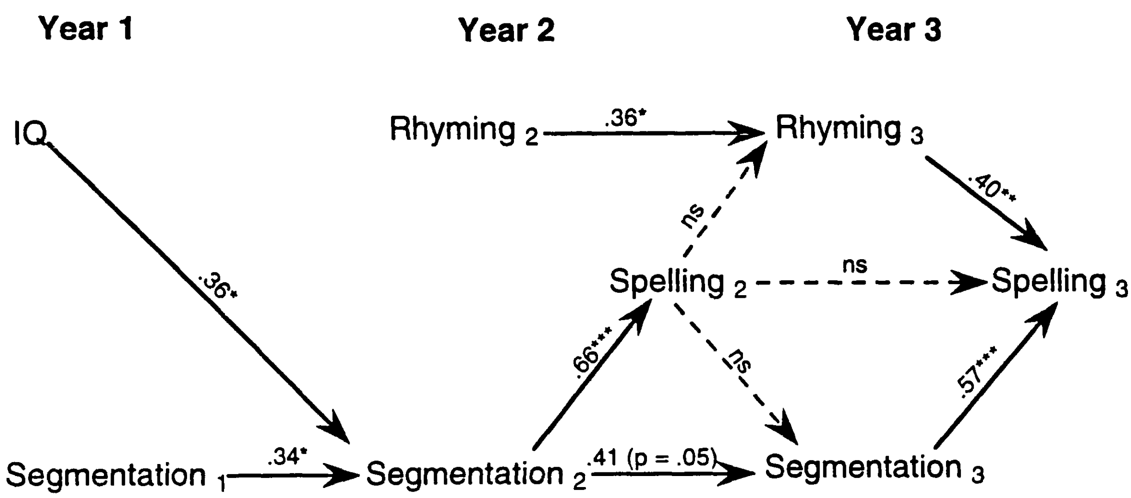

Figure 2.4
Path diagram depicting the relationship between Rhyming, Segmentation, IQ and Schonell Spelling during the first two years of learning to spell.

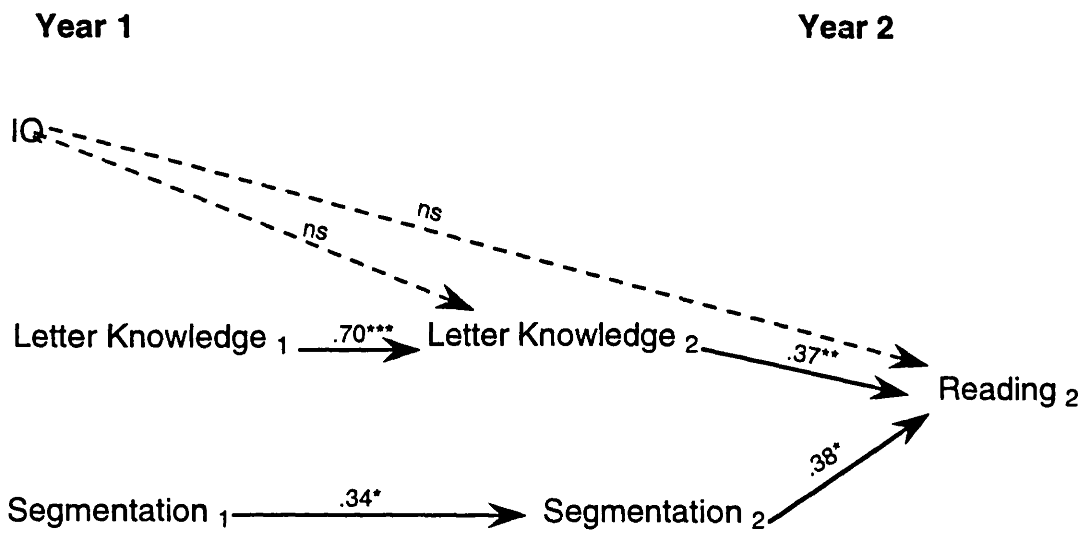

Figure 2.5
Path diagram depicting the contribution of Letter Knowledge, Segmentation and IQ to BAS Reading during the first year of learning to read.

Knowledge and Segmentation in Year 2 made a significant contribution to reading in that same year (β = 0.37, $p < .01$; β = 0.38, $p < .05$, respectively), having in turn been significantly influenced by Letter Knowledge and Segmentation from the previous year (β = 0.70, $p < .05$; β = 0.34, $p < .05$, respectively). A further Hierarchical Multiple Regression analysis looked at whether Letter Knowledge 1 had a direct effect on Reading 2; Letter Knowledge 2 was entered ahead of Letter Knowledge 1 and Segmentation 2. Letter Knowledge 1 did not significantly predict Reading 2 (β = 0.07, ns). Letter Knowledge 2's contribution was reduced to β = 0.33 (p = .08), but Segmentation 2 again remained highly significant (β = 0.47, $p < .01$). The Path Analysis was re-run, eliminating IQ from the right-hand portion of the path together with the direct path between Letter Knowledge 1 and Reading 2 (BAS). The resultant path diagram is shown in Figure 2.6.

There are both theoretical and empirical grounds for suspecting that segmentation ability and letter knowledge might not operate independently of one another i.e. that there might be an interaction between them such that the combined influence of the two factors is greater than their added separate effects. The Phonological Linkage Hypothesis and the empirical evidence from recent training studies described in Chapter 1 (Section 1.4.4) supports this supposition. To look at these interactive effects, three product variables were computed i.e. Year 1 Letter Knowledge x Segmentation, Year 2 Letter Knowledge x Segmentation and Year 3 Letter Knowledge x Segmentation.

A hierarchical multiple regression analysis was carried out entering Letter Knowledge 2 and Segmentation 2 simultaneously, followed by their product variable; the dependent measure was BAS reading. Figure 2.7 depicts the contribution of Letter Knowledge and Segmentation (in Years 1 and 2), together with their product variables, to BAS and Neale reading scores in Year 2. The separate contributions of Letter Knowledge and Segmentation remained highly significant (β = 0.40, $p < .01$; β = 0.38, $p < .01$, respectively). The product term was nearly significant (β = 0.23, p = .07). With the addition of the product term, R2Change was 4 percent. Thus, the interaction of Letter Knowledge and Segmentation made a small but unique contribution to early reading

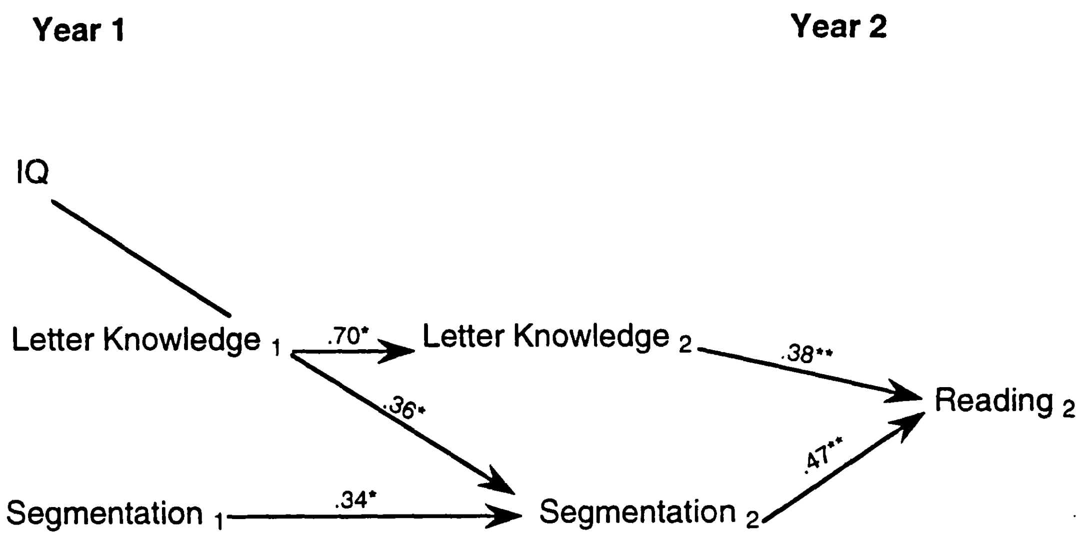

Figure 2.6
Path diagram depicting the contribution of Letter Knowledge, Segmentation and IQ to BAS Reading during the first year of learning to read (after removal of non-significant IQ paths).

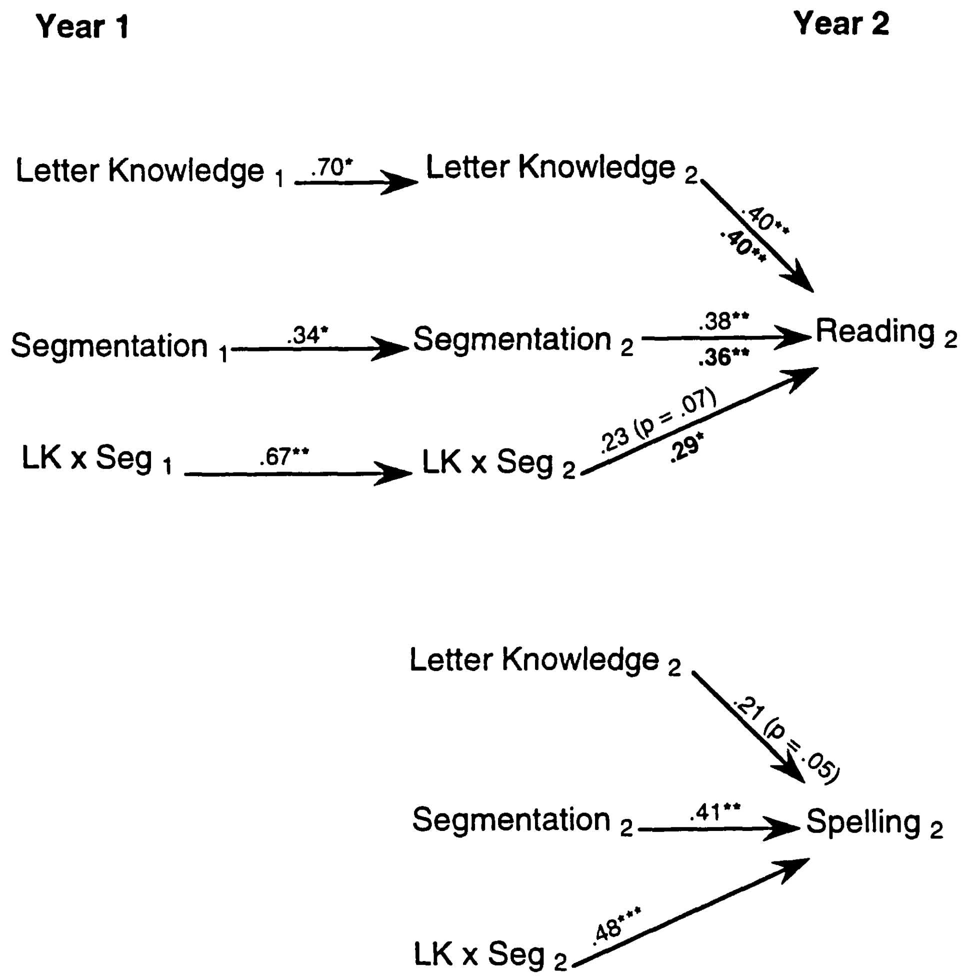

Figure 2.7
Path diagram depicting the contribution of Letter Knowledge, Segmentation and their Product Term (Letter Knowledge x Segmentation, LK x Seg) to BAS and Neale Reading and to Schonell Spelling during Years 1 and 2 of the study.

Emboldened print indicates Neale reading.

development, above and beyond the effects of the individual component skills. This effect was more pronounced when the analysis was repeated with Neale reading as the outcome measure. Letter Knowledge and Segmentation made significant separate contributions to Neale reading (β = 0.40 p < .01, and β = 0.36, p < .01, respectively). Now the product term emerged as significant (β = 0.29, p <.05). The linear combination of Letter Knowledge 2 and Segmentation 2 plus the product of these two variables accounted for around 60 percent of the variance in first year reading (both BAS and Neale).

The product term analyses were repeated with Schonell spelling as the outcome measure (Figure 2.7). Letter Knowledge 2 did not make a significant contribution to spelling (β = 0.19, ns). Segmentation in Year 2 was powerfully influential (β = 0.60, p < .001). When the product variable was entered after the two components, Segmentation 2 remained significant (β = 0.41, p < .01), Letter Knowledge 2 fell just short of significance (β = 0.21, p = 0.055), while the product term, Letter Knowledge x Segmentation 2, proved highly significant (β = 0.48, p < .001). With the addition of the product term R2Change was nearly 0.2 (20 percent). The linear combination of Letter Knowledge 2 and Segmentation 2 plus the product of these two variables accounted for nearly 70 percent of the variance in early spelling.

The analyses were then re-run to see if the product variable from Year 1 (Letter Knowledge 1 x Segmentation 1) had any direct effect on reading after entering the product variable from Year 2 and the individual variables. The Year 1 product variable did not contribute to Year 2 literacy development (β = -0.15, ns, for BAS reading, and β = 0.05, ns, for Neale reading). Year 2 Letter Knowledge, Segmentation and the product variable all remained statistically significant for both BAS and Neale reading (β = 0.40, p < .01; β = 0.40, p < .01; β = 0.29, p < .05, respectively for BAS reading; β = 0.40, p < .01; β = 0.35, p < .05; β = 0.27, p < .05, respectively for Neale reading). In the case of spelling, segmentation skills and the product term from Year 2 continued to make significant contributions (β = 0.40, p < .01; β = 0.45, p < .001, respectively), but the contribution of Letter Knowledge 2 fell just short of statistical significance (β = 0.21, p = .06). The Year 1 product term did not contribute to Year

2 spelling ($\beta = 0.07$, ns).

These analyses suggested that reading and spelling in first year Infants was a product of letter knowledge and phoneme segmentation skills. These skills operated in an independent and additive manner, but with an additional interactive effect, which was small for reading but very large for spelling. Letter Knowledge and Segmentation in Year 1 influenced the development of these same skills over the course of the following year which in turn then drove reading and spelling progress, but there was not a direct effect of Year 1 Letter Knowledge and Segmentation on reading and spelling a year later.

Previous analyses had demonstrated that segmentation skills did not have a bearing on Year 3 Reading (BAS and Neale). However, Letter Knowledge 2 contributed significantly to Letter Knowledge 3 ($\beta = 0.74$, $p < .001$), which in turn made a significant contribution to Reading 3 ($\beta = 0.27$, $p < .01$ for the BAS; $\beta = 0.26$, $p < .05$ for the Neale). The Year 3 product term contributed to neither BAS reading in that year ($\beta = 0.03$, ns), nor to Neale reading ($\beta = 0.05$, ns). Figure 2.8 illustrates the relationship between phonological awareness, letter knowledge and reading ability over the three years of the study.

In Year 3 Spelling, neither concurrent Letter Knowledge nor the product variable contributed to spelling progress in the final year of the study ($\beta = 0.14$, ns, for Letter Knowledge, and $\beta = 0.12$, ns, for the product term). Figure 2.9 summarises the relationships between phonological awareness, letter knowledge and spelling skills throughout the study.

2.3.3.3 Does visual memory have an influence on early reading and spelling development? Does it exert an effect additional to the powerful influence of Segmentation, Letter Knowledge and the Letter Knowledge x Segmentation product?

It was thought unlikely that visual memory would make a substantial contribution to reading development since the simple correlations between the visual memory tests and

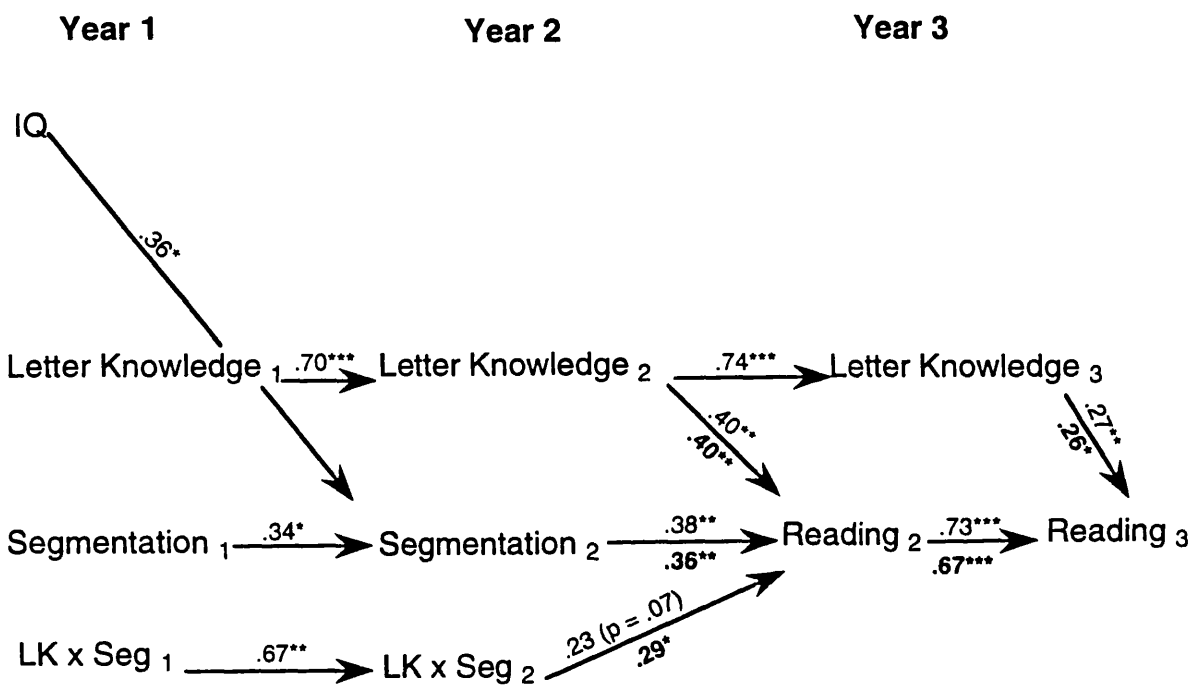

Figure 2.8
Path diagram depicting the relationship between Letter Knowledge, Segmentation, their Product Term (LK x Seg) and Reading (BAS and Neale) during the first two years of learning to read.

Emboldened print indicates Neale reading.

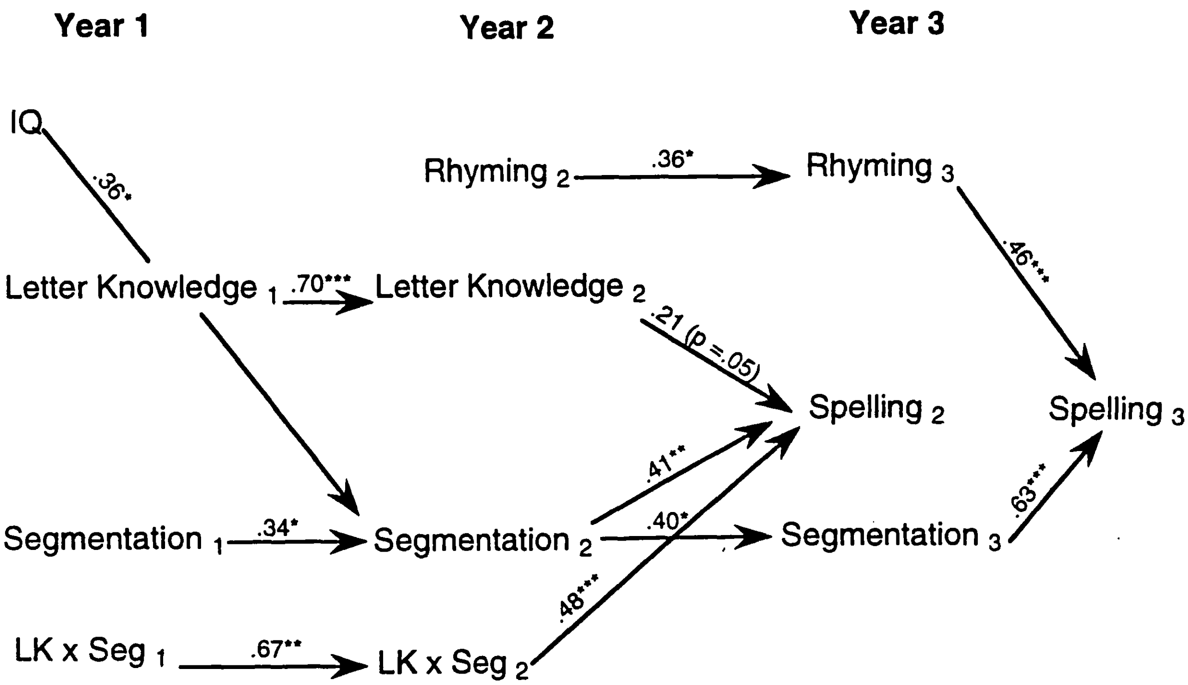

Figure 2.9
Path diagram depicting the relationships between Letter Knowledge, Segmentation, their Product Term (LK x Seg) and Schonell Spelling during the first two years of learning to spell.

the reading attainment scores in Years 2 and 3 rarely attained statistical significance, and even then at only modest levels (Table 2.4). However, it was suspected from the highly significant correlations obtained between visual memory and spelling in Year 2 (Table 2.4) that this relationship was worth exploring.

In the first Path Analysis looking at visual memory and spelling in Year 2, Letter Knowledge, Segmentation and the product term scores from that year were entered, together with the Visual Memory scores. Figure 2.10 showed that Segmentation and Letter Knowledge x Segmentation accounted for most of the variance in Year 2 Spelling (β = 0.36, $p < .001$; β = 0.44, $p < .001$, respectively), but that the contributions of Letter Knowledge and Visual Memory almost attained significance (β = 0.19, p = 0.07; β = 0.19, p = 0.07, respectively). When Letter Knowledge was excluded from the analysis, on the grounds of it having not quite achieved statistical significance, the contribution of Visual Memory increased marginally (β = 0.21, p = 0.05). Visual memory in Year 3 did not make a significant contribution to spelling in that year when it was entered into a multiple regression together with Rhyming and Segmentation (β = 0.03, ns).

It would thus appear that visual memory played a secondary, but just about demonstrable, role to that of letter knowledge and segmentation in influencing early spelling.

2.3.3.4 Does verbal short-term memory play a role in early reading and spelling development?

Multiple regression analyses were carried out using the Digit Span Scores from Years 1, 2 and 3, together with the Letter Knowledge, Segmentation and product variables in each of those years, and looking at the effects on reading (BAS and Neale) and spelling. Verbal memory did not make a significant contribution to any aspect of literacy in either Years 2 or 3 of the study: β = -0.03, ns, for BAS reading in Year 2; β = 0.05, ns, for Neale reading in Year 2; β = 0.07, ns, for spelling in year 2; β = 0.10, ns, for BAS reading in Year 3; β = -0.06, ns, for Neale reading in Year 3; β = 0.11, ns, for

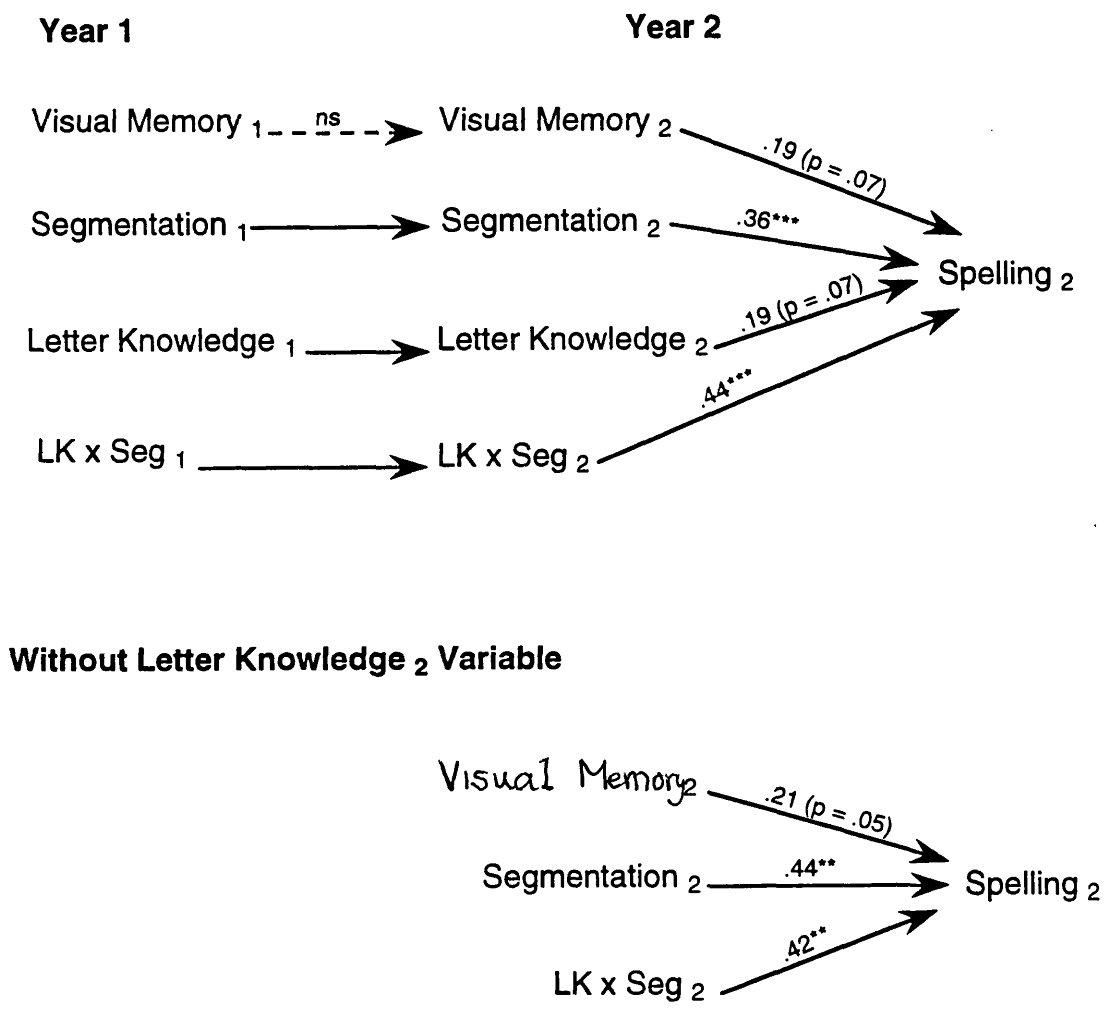

Figure 2.10
Path diagram depicting the contribution of Visual Memory, Letter Knowledge, Segmentation and LK x Seg to Schonell Spelling during Years 1 and 2 of the study.

spelling in Year 3. These findings suggest that verbal memory (as measured by a Digit Span test) does not play a significant role in influencing early reading and spelling development.

2.3.3.5 Are there reciprocal influences on reading development, specifically of reading and spelling over subsequent phonological awareness and verbal memory, and between reading and spelling themselves?

The effects of reading and spelling in Year 2 on the children's subsequent development of phonological awareness i.e. in Year 3 were studied. BAS and Neale reading ability in Year 2 significantly contributed to Rhyming 3 (β = 0.42, $p < .001$; β = 0.33, $p < .05$, respectively), but not to Segmentation 3 (β = -0.03, n.s. for BAS reading, and β = -0.05, ns, for Neale reading). Spelling 2 did not have a significant influence over rhyming or segmentation ability in Year 3 (β = 0.17, ns, and β = 0.05, ns, respectively).

It has been suggested that reading skills might influence the development of verbal short-term memory (Ellis, 1990). Multiple regression analyses showed that neither BAS nor Neale reading in Year 2 had a significant effect on verbal memory (as measured by Digit Span) in the following year (β = -0.11, ns, and β = 0.00, ns, respectively). Nor did concurrent BAS and Neale reading scores have a significant effect on verbal memory in Year 3 (β = 0.03, ns, and β = 0.00, ns, respectively).

The influence of spelling over reading development was assessed in a series of multiple regression analyses entering Spelling 2 or 3 together with BAS Reading 2 and Letter Knowledge 3. Spelling 2 did not predict Reading 3 (β = -0.02, ns), but Spelling 3 significantly contributed to Reading 3 (β = 0.33, $p < .01$).

BAS Reading 2 did not predict spelling one year later when entered into a multiple regression analysis together with the rhyming and segmentation scores from Year 3 (β = 0.19, ns). However, Reading 3 did make a significant contribution to Spelling 3 (β

= 0.43, $p < .01$). It could be argued that reading in Year 3 had a direct influence over spelling in the same year, but there was also an additional indirect effect of Reading 2 over Spelling 3 via its effect on rhyming processes; these patterns of influence are shown in Figure 2.11.

2.4 Discussion

2.4.1 The Development of Phonological Awareness

The present study demonstrated that phonological awareness shows a clear developmental progression during the ages of four to six years as children proceed from nursery through their first two years of formal schooling. In accord with the results of previous studies (see Adams, 1990, for a review), rhyming turned out to be the easiest task during the nursery year, followed by phoneme identification, then rhyme production, and finally phoneme deletion which proved very difficult indeed. The children's scores on all the phonological measures steadily improved during the course of the following two years, though on none of them did the mean score reach ceiling. It might be anticipated that had the study continued into the following year, the mean scores on the rhyming and phoneme identification tests would almost certainly have achieved ceiling, while the scores on the sound blending and phoneme deletion tests might just have fallen short of this upper limit. These results provide further evidence for the view that the more advanced stages of phonological awareness (e.g. phoneme segmentation and manipulation) are unlikely to be attained by the majority of children until they have received exposure to formal reading instruction, thus encouraging and promoting a two-way interactive process between phonological awareness and reading (Bryant and Goswami, 1987; Adams, 1990).

A series of Principal Component Analyses conducted on the phonological awareness measures during each of the three years of the study uncovered two relatively independent

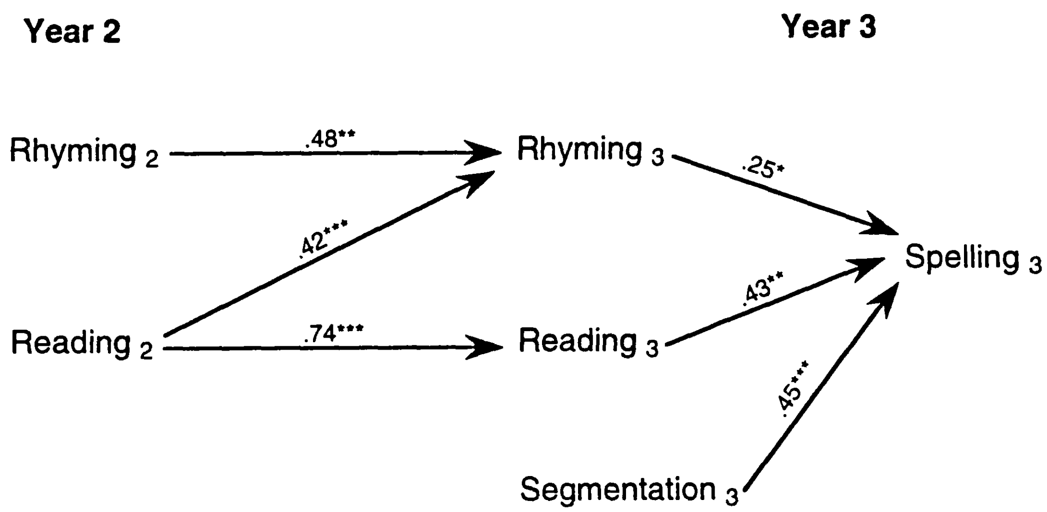

Figure 2.11
Path diagram depicting the relationships between Rhyming, BAS Reading and Schonell Spelling during Years 2 and 3 of the study.

(uncorrelated) factors. One was termed a Segmentation Factor on which the phoneme identification, phoneme deletion and sound blending tests loaded most highly. The other was interpreted as a Rhyming Factor since the rhyme detection and rhyme production tests loaded most highly on this factor. This study is thought to be the first to demonstrate empirically the existence of two essentially independent skills underlying early phonological awareness skills. However, previous studies have hinted at rhyming constituting a separate skill from other phonological abilities. In the study by Stanovich et al. (1984), their Principal Components Analysis revealed just one factor on which all the non-rhyming tests loaded highly. In Yopp's (1988) study the rhyming tests did not load highly on either of the two (correlated) factors uncovered in an oblique Principal Components Analysis. This led Yopp to propose that rhyming tests might well be measuring a different phonological ability than are most other phonological awareness tests. The present study provides evidence that supports Yopp's hypothesis. Yopp goes on to caution about reading research that draws its conclusions on phonological awareness from rhyme tasks. Goswami and Bryant (1990) take up this issue by, first, agreeing with Yopp that phoneme awareness and rhyming ability constitute separate and distinct subskills within the phonological domain. However, they disagree with her reservation about drawing conclusions from studies using rhyming measures, claiming that rhyme is more important than Yopp's caution would suggest. Goswami and Bryant have proposed that segmentation and deletion tests are measures of phonemic awareness, while rhyming tests are sensitive, not to individual phonemes within words, but to onset-rime units within words e.g. c-at (onset-rime distinction) as opposed to c-a-t (the phonemic structure of the word). Thus, one might expect rhyming and segmentation skills to exert quite different influences over subsequent reading and spelling development.

2.4.2 The First Year of Learning to Read and Spell

Further evidence for the distinct separateness of rhyming and segmentation skills comes from their differential effects during the first year of literacy development. The Path Analyses conducted in this study demonstrated that segmentation made a highly significant contribution to early reading and spelling, while rhyming did not. The process is one whereby IQ and pre-school segmentation ability both contribute to segmentation skills in the following year which then, in turn, drive reading and spelling progress during the first year at school. The effect of IQ on reading is not direct, but rather it exerts its influence through segmentation ability i.e. brighter children find segmenting words into phonemes easier than less bright children, and it is the skill in segmentation which promotes reading development. It may seem incongruous that IQ does not play a greater role in early reading and spelling development. However, this is in accord with the results of previous studies (summarised in Adams, 1990) which have indicated that, at least as far as reading is concerned, IQ comes in third, after phonological awareness and letter knowledge, in the prediction of early literacy success (Chall, 1967; Bond and Dykstra, 1967). This is not to say of course that IQ need not contribute to later reading development as contextual and comprehension factors come to play an increasingly important role. In a two-year longitudinal study conducted by Tunmer (1989), decoding skills were shown to be critical in the beginning stages of reading, with comprehension becoming more important later on, after children had mastered the basic decoding skills.

In keeping with the findings of other studies (Chall, 1967; Bond and Dykstra, 1967), letter naming knowledge proved a powerful contributor to reading and spelling processes during first year infants. Segmentation and letter knowledge made separate and specific contributions to both early reading and spelling, with an additional significant contribution from the product term (Letter Knowledge x Segmentation) that reflected the interaction of the two component skills. The product term exerted a small additional influence on reading, but a massive effect on spelling.

The present findings may be considered within the framework of Goswami and Bryant's developmental model of early reading and spelling development (Goswami and Bryant, 1990). They have proposed that there are three causal components in beginning literacy: phonological awareness skills that begin to develop during the preschool period; exposure to an alphabetic script, and; the link between reading and spelling which, after an initial period of separate and distinct development, emerges about two years after reading instruction begins. The results of the present study provide support for the existence and salience of the first two causal components.

Goswami and Bryant (1990) have elaborated on the role of specific phonological awareness subskills and their contribution to early reading and spelling development. They have hypothesised that rhyming skills predict reading through their influence on children's awareness of the onset-rime distinction. However, phoneme segmentation skills predict spelling through their effects on children's ability to break up words into phonemes when they write. Bryant, MacLean, Bradley and Crossland (1990) were able to demonstrate longitudinally that rhyming (as measured by the Bradley oddity test) made a direct and independent contribution to reading, while segmentation (using a phoneme deletion test) made a direct and separate contribution to spelling. Cataldo and Ellis (1988) have provided independent evidence that supports the Goswami and Bryant view. They adopted the Bradley Test as a measure of Implicit Phonological Awareness which they defined as "global awareness of the sound properties of words" (p. 93). A test of phoneme segmentation was purported to measure Explicit Phonological Awareness or "the explicit awareness of individual sounds within words" (p. 93). In a longitudinal study of beginning reading and spelling, Cataldo and Ellis found that explicit phonological awareness was initially dissociated from reading, although implicit phonological awareness made a significant contribution to the very early stages of reading development. However, explicit phonological awareness exerted a strong influence from the very outset of spelling acquisition that was maintained throughout the duration of the study.

In the present study, rhyming failed to significantly contribute to reading or spelling during the children's first year in school. Rather, it was phoneme segmentation abilities that critically influenced the onset of both reading and spelling development. These results contradict the Goswami and Bryant hypothesis that proposes separate and distinct contributions of rhyming and segmentation to early reading and spelling respectively. In agreement with the present findings, Tunmer, Herriman and Nesdale (1988) showed that phoneme segmentation ability (children's performance on a phoneme tapping test) contributed to reading skill during the first year of learning to read. Goswami and Bryant (1990) have criticised the Tunmer et al. study by drawing attention to the fact that only one measure of phonological awareness was employed. They comment "There would, we predict, be quite a different pattern of results if the children were given a rhyme test as well as a phoneme test" (p. 115). The present study has overcome this objection by adopting demonstrably independent measures of rhyming and segmentation.

The Bradley (oddity) Test is regarded by Cataldo and Ellis (1988) as a measure of global awareness of sounds, whereas Goswami and Bryant (1990) view it specifically as a test of rhyming. In reality, it is a highly complex task comprising aspects of phonological awareness and possibly also of phonological working memory (Wagner and Torgesen, 1987). Consequently, it could be argued that it is not a pure and unambiguous test of rhyming ability. It is, therefore, difficult to be sure that the critical factor being measured is onset-rime awareness. The present findings have shown that when rhyming is measured in a direct and unambiguous way, it does not appear to have a causal influence over beginning reading development. Yet different measures of phoneme segmentation (whether deletion, blending or identification in the present study, or tapping in the Tunmer et al. study) strongly predict first year reading and spelling acquisition.

It seemed probable that the present study was capturing the majority of children at that point in their literacy development when they were beginning to acquire the "alphabetic principle" i.e. the knowledge that particular phonemes in words are represented systematically by particular letters (Byrne and Fielding-Barnsley, 1989). According to Ehri (1992), this knowledge is achieved when children have had sufficient exposure to letters presented in graphemic form, and after they have attained a level of phonological awareness that enables them to split words into their component sounds. It is the acquisition of the alphabetic principle that enables the child to proceed from the logographic to the alphabetic stage in reading development (Byrne and Fielding-Barnsley, 1989). If the child's usable knowledge about speech structure does not include the phonemic principle he or she will read logographically at first (the "default option", Byrne, 1992). In other words, the child will build up an idiosyncratic sight reading vocabulary by paying attention to salient visual cues within words. This method of reading can be circumvented if the child has access to a mental representation of speech at the level of the phoneme and knows how letters symbolise phonemes. Consistent with this view is the finding of Stuart and Coltheart (1988) who demonstrated that many children do not adopt logographic reading strategies at all but use phoneme-to-grapheme correspondences from the beginning.

However, it is not just a question of the children achieving the reading related skills of phonological awareness and graphemic knowledge in a purely additive fashion. Training studies (Bryant and Bradley, 1983; Ball and Blackman, 1988; Cunningham, 1988; Hatcher, Hulme and Ellis, in press, 1994) have shown that children make most progress in reading when phonological awareness training is combined in a meaningful way with the learning of letter names and sounds. It is this combination which is reflected in the product term, Letter Knowledge x Segmentation. Phonological awareness training and teaching letter-sound relationships may help improve children's reading, but when they are both taught, or even better taught in combination, the effect on progress is significantly enhanced. The especially pronounced effect of the product term in spelling (as opposed to the more modest influences in reading) is consistent with the view that the alphabetic approach has more salience for early spelling than reading (Bryant and Bradley 1980, 1983). The clear demonstration of positive contributions from segmentation and letter knowledge to early literacy progress, and more importantly, the additional influence of the interactive effect of these two skills supports the Phonological Linkage Hypothesis proposed by Hatcher, Hulme and Ellis (in press, 1994), that to optimise progress in reading, it is necessary to teach children in such a way that explicit links are formed between children's underlying phonological awareness and their experiences in learning to read. The extent to which linkage has occurred, as measured by the additional variance accounted for by the product term in this study, predicts success in early reading and, more particularly, spelling development.

Visual memory skills, evaluated with a reading-relevant test of recall of letter-like forms, failed to correlate with early reading progress. This is in apparent contradiction to the results of studies that have demonstrated predominantly visual processes in early reading (Bryant and Bradley, 1983; Kimura and Bryant, 1983; Johnston, Anderson, and Duncan, 1991). It may be that the present study had too few children adopting the default option of reading logographically in Year 1 to register a significant connection between visual memory and reading. Visual memory played a small (but barely significant) role in the earliest stage of learning to spell. It could be argued that, because written English is not entirely regular, children need to store a visual representation of the word and its letter sequences in order to achieve accurate spelling. However, it is clear from the present findings that the role of visual memory in the first year of learning to spell is very minor when compared to the massive influence of segmentation ability, letter knowledge and their combined effect. Alternatively, the significance level for visual memory and its contribution to spelling might reflect individual differences in the degree to which visual strategies are used in early spelling. Some children who have relatively poor segmentation and letter knowledge skills may well rely heavily on visual representations of words they spell; it is this minority of children who might be reflected in the modestly significant finding for visual memory and early spelling.

Verbal short-term memory did not significantly contribute to progress in reading and spelling during the first year at school. However, it could be argued that a digit span test is not as reading-relevant nor as sensitive a measure of phonological working memory as for instance a word span or speech rate test. McDougall, Hulme, Ellis and Monk (in press, 1994) found that both phonological segmentation and speech rate (a measure of the speech-based rehearsal component of short-term memory) made separate and direct contributions to differences in reading ability.

Notwithstanding these criticisms, the present findings are in direct contradiction to the conclusions of the longitudinal study conducted by Gathercole, Baddeley and Willis (1991) in which phonological memory was found to exert a highly significant influence over early reading development. One possible criticism of the Gathercole et al. study is that their test of phonological memory (a nonword repetition test) assesses not only memory processes, but also phonological segmentation and possibly assembly of articulatory instructions (Snowling, Chiat and Hulme, 1991). It may be that what Gathercole et al. were picking up was an effect of phonological segmentation on reading development, not pure memory per se. Indeed, a difficulty with any study that investigates both phonological and memory processes in reading is that of separating them out and measuring the skills independently of one another (Hulme and MacKenzie, 1992). Some phonological awareness tests (Bradley's oddity test) contain a sizeable working memory component, while certain measures of working memory (nonword repetition tests) are often simultaneously tapping phonological skills such as segmentation. The present study employed phonological awareness tests that were not heavily memory-loaded (by allowing "picture support"), and a short-term memory test that did not have a major phonological component. It is clear that these results favour the position that phonological segmentation processes make a significant contribution to beginning reading while verbal memory skills, when assessed independently, do not.

2.4.3 The Second Year of Learning to Read and Spell

Phonological awareness skills showed markedly different effects on reading and spelling by the second year of learning to read. Neither second nor third year rhyming or segmentation skills made a contribution to BAS and Neale reading scores in the second year at infants school. However, the children's reading vocabulary of the previous year exerted a powerful influence over their reading development into Year 3 of the study. This seemed to indicate that the children were in some way using their existing vocabulary base, in a way that was independent of their phonological awareness, to develop further reading skills.

The interpretation of these findings is at this stage speculative. It could be that the children had entered a "consolidation" phase after establishing the alphabetic principle during their first year or so of learning to read. Alternatively, these results might reflect the development of a sight reading vocabulary through visual-phonological connections, proposed by Ehri (1992). In her view, children set up connections between sequences of letters in printed words and the phonemes that represent them. The connections are formed out of the reader's knowledge of sound-letter correspondences and of orthographic regularities abstracted through his or her reading experiences. Children use these connections that have been set up in memory in order to directly access the pronunciations of words. This process omits the intermediate stage of applying grapheme-to-phoneme correspondence rules and is consequently faster and more direct. The path diagram of Figure 2.8 indicated that the major contributors to reading progress in Year 3 were reading vocabulary from Year 2 together with letter knowledge in Year 3. Consistent with Ehri's model is the view that the child is continuing to make more sound-letter correspondence associations (Letter Knowledge 3) and using his or her established reading lexicon to draw inferences about orthographic regularities (Reading 2). These two processes in combination then fuel further reading development but without a phonological component, which had it played a role would have been reflected in significant contributions to Year 3 reading from segmentation and the Letter Knowledge x Segmentation product term.

In contrast to the findings in reading, phonological awareness continued to exert a powerful influence on spelling throughout the first two years at school. Not only did segmentation persist in its contribution to spelling, but rhyming entered the picture also. The development of phoneme segmentation skills could be depicted as a continuous progression in that segmentation abilities from a previous year always significantly contributed to the more refined version of the same ability a year later. Segmentation ability contributed to Year 2 spelling on its own, and additively in combination with letter knowledge. In Year 3, segmentation skills continued to play an important role in spelling, but the product term no longer exerted a direct additional influence. It seemed as though, once the alphabetic principle had been established through reading and writing experience in Year 2, the children proceeded to a subsequent stage in which segmentation skills continued to exert an effect but not in relation to simple letter-sound knowledge. Rhyming as a contributory skill did not become a viable force until Year 2, far later than would be predicted from the Goswami and Bryant (1990) model. The children's rhyming ability in Year 3 appeared to arise from their rhyming competence in the previous year and their earlier reading ability (Figure 2.11). Rhyming in Year 3 then significantly contributed to spelling progress in that same year. Unlike the pattern of influence in reading, Spelling 2 did not contribute to Spelling 3. It may be that the children's spelling vocabulary in Year 2 was more limited and idiosyncratic than in reading, and so could not form a sufficiently usable base on which to build a more advanced vocabulary in the following year.

Although not directly assessed in this study, it is probable that rhyming and segmentation contribute to quite different aspects of the spelling process. In line with the Goswami and Bryant model, it could be hypothesised that rhyming skills promote the awareness of the onset-rime distinction within words which may in turn influence children's use of analogy in spelling. In contrast, segmentation abilities promote the awareness of phonemes within words which then facilitate children's ability to make use of phonemic encoding principles in spelling. The present findings would support the view that children apply grapheme-to-phoneme correspondences in their early spelling attempts, but then later on begin to take note of larger segments in words, probably of analogy/onset-rime units. Wimmer, Landerl and Schneider (1991) drew similar conclusions from their longitudinal study of early literacy development in German-speaking Austrian children. These authors found that rhyme awareness was only minimally predictive of reading and spelling achievement at the end of Grade 1, but that it gained substantially in predictive importance for reading and spelling achievement in Grades 3 and 4. They proposed that rhyme awareness was initially of little importance because the children, who were taught a phonics reading system, relied heavily on grapheme-phoneme translation and blending in Grade 1. In the later grades, rhyming gathered in predictive significance because it seemed to promote the children's awareness of larger phonological units within words. These in turn connect with mental representations of recurring grapheme clusters and so enable fast direct word recognition.

The developmental time course attributed to the awareness and use of onset-rime and phoneme boundaries within words has generated disagreement and controversy. It is well established that, at the level of speech, awareness of the syllable precedes that of the phoneme (Liberman, Shankweiler, Fisher and Carter, 1974). It is also argued that onset-rime awareness precedes awareness of the phoneme (Treiman, 1985; Kirtley, Bryant, MacLean and Bradley, 1989). However, Seymour and Evans (1991) have taken issue with this view. They demonstrated that children who were taught sound-to-letter correspondences found it easier to segment words into phonemes rather than into their onset-rime units. While it is generally acknowledged that onset-rime awareness is a skill available to beginning readers, it does not necessarily follow that they make use of this knowledge when reading and spelling. Goswami and Bryant (1990) have argued the case for children being taught onset-rime and analogy principles in reading and spelling prior to being introduced to phoneme segmentation strategies. However, Ehri and Robbins (1992), Bruck and Treiman (1992), and Seymour and Evans (1991) have expressed reservations about this, arguing that the adoption of a fixed order of teaching methods might be premature in the light of recent evidence. Ehri and Robbins (1992) and Bruck and Treiman (1992) found that young children need some knowledge of grapheme-to-phoneme correspondence before they can make effective use of analogies in reading. Seymour and Evans (1991) have suggested that children's ability to segment words into onset-rime or phonemic units is influenced by method of instruction. The present findings add weight to the cautious views expressed by these authors. It is suggested that Goswami and Bryant have overestimated the importance of rhyming and analogy in early literacy development, at the expense of phoneme segmentation skills which the present study found exerted an earlier and more pervasive influence over beginning reading and spelling.

The findings are consistent with the view that phonological awareness, in combination with children's reading experiences and growing lexicon, drives further development in literacy skills. The existence of a complementary relationship, in which reading and spelling have the effect of further refining phonological awareness skills, receives some support from the present study. Certainly, reading in Year 2 promoted the development of rhyming skills in the following year. It might be argued that children respond to some phonological awareness tests by generating an orthographic image of the word, mentally manipulating the word's letters and then reading the result in their mind's eye (Tunmer and Hoover, 1992). However, reading did not have an effect on subsequent segmentation skills, and spelling in Year 2 did not influence later phonological awareness. It would appear that, while there is indeed a reciprocal relationship between literacy and phonological awareness development, nonetheless the strongest and most consistent influence is that of phonological awareness over reading and spelling, with lesser effects operating in the reverse direction.

Reading and spelling may proceed along somewhat different routes in different stages of their development, but this does not mean that they operate independently of one another.

In the present study, reading and spelling contributed to each other's concurrent outcome in Year 3. It was not possible to demonstrate a predictive effect from Year 2 reading and spelling to Year 3 spelling and reading, respectively. Cataldo and Ellis (1988) demonstrated a one-way transfer of knowledge from spelling to reading in their longitudinal study of 40 beginning readers. They went on to suggest that children's experience in spelling promotes the use of a phonological strategy in reading. The present study seems to provide stronger evidence not so much for the reverse direction of influence, but for an indirect effect of reading in Year 2 over spelling in Year 3 via reading's contribution to rhyming a year later and then rhyming's direct effect on spelling. It could be argued that learning to read promotes children's awareness of onset-rime boundaries within words which in turn helps them to rhyme more proficiently. Rhyming then influences spelling, again perhaps by drawing children's attention to the onset-rime structures within words they are attempting to spell.

The present study has demonstrated that the effects of phonological awareness are specific to reading and spelling, and that they do not exert a generalised influence over educational development. Neither rhyming nor segmentation in the same or the previous year contributed to oral arithmetic skills in Year 3. These phonological awareness skills appeared to influence written arithmetic but this effect disappeared after the children's reading skills were entered into a multiple regression ahead of rhyming and segmentation. It seems plausible that reading ability would significantly influence progress in written arithmetic, since one would expect a strong correlation between children's knowledge of, and ability to read, letters and words, and their proficiency in "reading" numbers and arithmetical symbols.

Verbal short-term memory did not exert a direct effect on reading or spelling development in Year 3 of the study. Nor did BAS or Neale reading scores in either Years 2 or 3 contribute to verbal memory functioning in Year 3 (as Ellis, 1990, might predict). Recent models (Shankweiler, 1989; Crain, 1989, Shankweiler, Crain, Brady and Macaruso, 1992)) view verbal memory as an integrated component within a phonologically-based information processing framework. It is the development of efficient phonological processing which helps to ensure the optimal flow of information from reading stimuli up to higher levels within the system. Verbal memory problems are thus conceptualised as restrictions or bottlenecks within the system arising from inefficient phonological processing. The interaction of verbal memory and phonological processes within this integrated system, and their (possibly reciprocal) influence on reading development, is an area in need of further research.

Visual memory processes made no contribution to Year 3 spelling. By the second year of schooling, it is unlikely that other than a very few children would have still been adopting a logographic default option in either reading or spelling. Their preference for visual strategies would have been well masked by the majority of children proficient in using phonologically based reading and spelling strategies. It is of course possible that visual skills might play a greater role in later, middle childhood, reading and spelling processes. Finally, there remains the possibility that the visual recall test employed was not measuring the kind of visual memory processes needed to promote early literacy progress. A test of recall of letter-like forms would seem to be a more reading relevant task than say a test of memory for pictures. However, early visual processing in reading/spelling may take a number of different forms; the child might be responding to the word as a holistic visual shape, he or she might be processing a sequence of letters, or finally, the child might be responding (quite idiosyncratically) to isolated salient visual features within the word e.g. its length, specific letters or groupings of letters. The capacity of a single visual memory test to evaluate these different visual processes, in which there may be marked inter-subject variability, is called into question.

2.5 Conclusions

The present study has shed light on a number of controversial issues pertaining to cognitive processing during the early phases of literacy development. Firstly, it has been established that phonological awareness comprises two separate (relatively uncorrelated) underlying processes, specifically of phoneme segmentation and rhyming, that exert differential influences over early reading and spelling development. Segmentation ability has a powerful effect on the first year of learning to read and spell and so (roughly equally) does letter knowledge. This result adds weight to the findings of training studies demonstrating that it is the acquisition of the alphabetic principle, which in turn depends on a minimal level of phonemic awareness and knowledge of at least some sound-to-letter correspondences, that propels children into and through the early phases of literacy development. However, there is an additional effect of the Letter Knowledge x Segmentation product term which is over and above the influences of the separate constituent skills. The product term reflects the interaction of segmentation abilities and letter knowledge i.e. the potentiating effect they have on each other, and is especially powerful in spelling. It offers a direct measure of the size of the linkage component described in the Phonological Linkage Hypothesis, whereby children are thought to make more progress in reading and spelling when phonological awareness training is combined in a meaningful way with literacy experiences.

The finding that reading and spelling are affected by different cognitive processes by the second year at school is consistent with the view of several authors, notably of Bryant and his colleagues, who believe that early reading and spelling proceed along different routes. The results for reading appeared to capture the consolidation of a sight reading vocabulary very much along the lines proposed by Ehri. Once children have established the alphabetic principle, as indeed they had in Year 2 of the study, they have less need to apply phoneme-to-grapheme translation rules. Rather, they begin to use their improving knowledge of sound-to-letter relationships, and their increasing awareness of orthographic regularities to read words by visual-phonological connections. This process is faster and more direct than one involving repeated use of translation rules, does not rely so heavily on phonemic awareness, but builds instead on the child's reading experience. Spelling, however, appears to remain more phonologically bound, with both segmentation and rhyming influencing the second year of learning to spell. In line with Goswami and Bryant's hypothesis, it may be that the children's segmentation abilities promote their phonemic awareness as children "sound out" words they are asked to spell e.g. "cat" is spelled "c-a-t". Rhyming, which emerges as a later influence, might concentrate children's attention on the onset-rime boundaries of words e.g. "cat" is spelled "c-at", eventually promoting the adoption of analogical principles to words that share the same rime e.g. "cat, rat, sat, mat".

Chapter 3

Orthographic Analogies and Phonological Awareness: their Role and Significance in Early Reading Development

3.1 Introduction

The longitudinal study described in Chapter 2 highlighted the importance of phonological segmentation skills, as opposed to rhyming ability, in the promotion of early reading development. The failure to establish a strong link between rhyming and reading may be partly attributable to the nature of the dependent measures employed; in the case of the longitudinal study reported, these were standardised tests of reading. However, it is possible that different levels and types of phonological awareness affect different aspects of literacy development. Chapter 3 describes an experimental investigation of a particular process in reading, that of analogy. The influence of specific phonological awareness skills, including rhyming, over the children's ability to apply analogical principles in reading was studied within the framework of the larger longitudinal study.

The traditional dual-route model of reading, discussed at some length in Chapter 1, proposes that there are two possible ways of reading a given word (Coltheart, 1978). One way is <u>direct access</u> in which the letter identities of a printed word are used to access its orthographic representation in the mental lexicon; this route applies to the reading of familiar words. The alternative strategy is by <u>indirect access</u> in which the letter identities of a printed word are first segmented into graphemes, after which a phonological representation is assembled by applying grapheme-to-phoneme correspondence rules; this strategy can be applied to the reading of regular words and nonwords.

More recently, a third possible mechanism for reading, that of <u>analogy</u>, has been described (e.g. Glushko, 1979). When reading by analogy, readers synthesise the pronunciations of new words based on their knowledge of known words with similar spelling patterns. This mechanism may be very important in learning to read. Thus, a child who knows how to read the word "beat" can, through the process of analogy, infer the pronunciation of similarly spelled words like "meat, heat". Marsh et al. (1980) proposed that analogical processes could be used by readers in the final stage of reading development. However, in a series of elegant experiments, Goswami has challenged this view that analogies can only be used by older children and adults (see Goswami and Bryant, 1992, for a review).

Goswami (1986) devised an experimental paradigm for demonstrating young children's ability to analogise, a basic methodology that has been maintained throughout her work, and which is adopted in the present study. She presented five- to six-year-old children with a clue word e.g. "beak", and then asked them to read other words, some of which were analogues of the clue word e.g. "peak, weak", while others were control words that could not be read by analogy but were equally visually similar in that they shared three letters e.g. "lake, pake". Goswami found that the beginning readers read correctly more analogy than control words. Moreover, young children made more analogies in reading when the shared letter sequence was at the end of the word than at the beginning; more analogies were made between "beak" and "peak" than between "beak" and "bean". Goswami (1991) extended this work to show that children find it easier to make analogies when the onset-rime distinction within a word is preserved. Her subjects made more analogies when reading new words with shared consonant clusters at the beginning such as <u>tr</u>im, <u>tr</u>ap (where the cluster corresponds to the complete onset) than at the end as in wi<u>nk</u>, ta<u>nk</u> (where the cluster is part of the rime).

According to Goswami (1986), the majority of five-year-olds who were able to make analogies successfully could read none of the words in a standardised reading test. Thus, children's ability to make use of analogy did not appear to be dependent on existing reading skill. However, this conclusion has come under attack from Ehri and Robbins (1992) and from Bruck and Treiman (1992). These studies and their implications for Goswami's work are discussed in some depth in Chapter 1 (section 4.2). In short, these authors found that a rudimentary reading vocabulary, and very possibly basic phonic decoding skills, need to be present before young children can reliably read words by analogy.

In the majority of Goswami's experiments, children trained on the clue words were allowed to refer back to them during the analogy post-test phase. Indeed, they were encouraged to do so. An exception to this was one experiment in which 24 six-to-seven year old children were trained on a pair of analogy words to a criterion of two consecutive correct responses (Goswami, 1988, Experiment 2). The training made explicit reference to the common spelling sequences in the analogy words, and encouraged the use of an onset-rime breakdown. An analogy effect was obtained without the clue word being exposed at post-test. However, this experiment did not systematically vary whether or not the clue word was exposed at post-test. It is, therefore, not possible to estimate the extent to which children are dependent upon the clue as a referent when they make analogies. A more powerful case could be argued for children's early use of analogy if it could be demonstrated that they can apply the analogy principle to new words without having to be prompted to do so, or needing to have their attention drawn to onset-rime units in words. It cannot be inferred that a reading strategy demonstrable in an experimental (and, therefore, necessarily, artificial) setting is spontaneously used by children in their real-life reading experiences. In short, we need to be cautious before accepting that beginning readers have access to analogy as a strategy for reading which they employ naturalistically.

Finally, Goswami (1990) has hypothesised that there is causal link between early rhyming ability and children's subsequent use of analogy in reading. Goswami (1990) and Goswami and Mead (1992) demonstrated a close relationship between rhyme awareness and the ability to analogise, especially the making of end analogies (see Chapter 1.4.2). Both these studies were cross-sectional, and thus were restricted to making inferences about the existence of a relationship, but not its direction. Clearly, longitudinal data, in which rhyming measures are obtained prior to the demonstration of analogy effects, are needed in order to establish both the presence of a relationship and its direction.

3.2 Experiment 1

Experiment 1 was designed to assess the extent to which children are dependent upon clues when using an analogy strategy in reading. The paradigm chosen was that developed by Goswami (1986). Following a pre-test, subjects were taught the pronunciation of clue words. After this came post-test trials in which the children were encouraged to read a series of words analogous with each clue, together with control words. In this experiment, half of the subjects had the relevant clue word exposed at post-test (c.f. Goswami, 1986), while the other half did not.

3.2.1 Method

3.2.1.1 Subjects

Thirty six of the 38 children who were being studied longitudinally (see Chapter 2) participated in this experiment. The analogy experiment was carried out at the third test when the children were six years old and in their second year at Infants School. At that time, the children ranged in age from 5 years 9 months to 6 years 8 months, with a mean age of 6 years 3 months. Their mean IQ, based on four Verbal and four Performance subtests of the Wechsler Preschool and Primary Scale of Intelligence, WPPSI (Wechsler, 1963), was 114.67, with a standard deviation of 10.68. The children ranged in reading age from 5 years 0 months to 7 years 8 months, with a mean reading age of 6 years 2 months (British Abilities Scales Word Reading Test, Elliott, Murray & Pearson, 1983).

3.2.1.2 Design and Materials

At the beginning of the experiment, the children were <u>pre-tested</u> on a list of words comprising analogy and control items. They were then <u>trained</u> to criterion on a series of clue words on which the analogy words were based. The children were randomly allocated to one of two groups at <u>post-test</u>. Half of the subjects had the relevant clue word exposed at post-test while the remaining half were tested without being able to look back at the clue word.

To exclude the possibility of obtaining word-specific effects, two sets of matched words were used (List A and List B). Half of the subjects received List A and the other half List B. In List A, the clue words were ring, back, land, told and neat. In List B, they were rang, sock, sent, mind and tail. The analogy words all contained the same rime unit as the clue, but differed in the onset (e.g. ring-king, mind-kind). The control words had three letters in common with the clue words with which they were linked, were of comparable length, but could not be read by rime analogy. The clue, analogy and control words, together with their Kucera-Francis frequencies (Kucera & Francis, 1967), are given in Appendix 3.1.

All the children were taught five clue words and attempted to read a total of 20 analogy and 20 control words at pre- and post-test. At pre-test, the order of presentation of the 40 words was completely randomised. At post-test, the words were presented to the children in blocks of eight; the four analogy and the four control words for a given clue word were randomly interspersed. The order of presentation of the blocks was randomised across all subjects.

3.2.1.3 Procedure

All the children were pre-tested on the list of analogy and control words on which they would be re-tested after training. After pre-testing, the children were trained on five clue words. These were presented on individual flashcards, with the children told by the experimenter what each word said. The words were then shown again, this time for the child to read. If he or she was unable to read a word, the experimenter supplied the correct pronunciation. All the children were trained to a criterion of five words correct on three consecutive trials. There was considerable variability in the time taken to learn the clues, but as a general rule the maximum time spent training each child was 10 minutes. They were then given the analogy and control words to read at post-test. They were told that the words they had just learned "could help them read some of the new words". Half the children had the clue word exposed while they were shown each set of four analogy and four control words; this provided them with a visual prompt, but no reminder of the pronunciation of the word was given by the experimenter. The other half did not have the clue word exposed during this phase of the experiment. The experiment was conducted in one session lasting approximately 20 minutes for each child.

3.2.2 Results

Initial analysis of the data indicated that the effect of List was not significant ($F[1,32] = 0.05$, n.s.). The data were, therefore, collapsed across List, and the children's performance at pre- and post-test was analysed using a mixed design analysis of variance (see Table 3.1). There was one between subjects variable (Clue Exposure), and two within subjects variables (Word Type and Pre/Post Test).

Table 3.1 Mean number of words read correctly in Experiment 1 (maximum - 20).

		Word Type	
		Analogy Words	**Control Words**
Clue	**) Pre-Test**	4.50 (5.09)	4.00 (5.32)
Exposed	**) Post-Test**	9.00 (6.68)	4.38 (5.16)
Clue Not	**) Pre-Test**	2.11 (3.97)	1.00 (1.80)
Exposed	**) Post-Test**	4.17 (5.47)	1.61 (2.57)

Standard deviations in parentheses.

There was a significant main effect of Word Type ($F[1,34] = 32.97$, $p < .001$), indicating that the children read more analogy than control words. The effects of Pre/Post Test ($F[1,34] = 34.08$, $p < .001$) and of Clue Exposure ($F[1,34] = 4.59$, $p < .05$) were also significant, as was the interaction between Pre/Post Test and Word Type ($F[1,34] = 24.45$, $p < .001$). There was an important three-way interaction between Clue Exposure, Word Type and Pre/Post Test ($F[1,34] = 5.63$, $p < .05$).

Tests of simple main effects indicated that the difference between the analogy and control words was greater at post-test than at pre-test ($F[1,34] = 24.45$, $p < .001$). This effect was relatively more pronounced in the group that had the clue exposed at post-test ($F[1,34] = 26.78$, $p < .001$) than in the group that did not ($F[1,34] = 4.40$, $p < .05$).

Inspection of Table 3.1 revealed that the children who were exposed to the clue word at post-test had higher pre-test scores on both the analogy and control words than did the children who were not exposed to the clue. To ensure that the differences between the groups at post-test could not be accounted for by differences existing at pre-test, an analysis of the post-test scores was carried out using the children's pre-test scores as covariates. Once again, there was a significant effect of Word Type ($F[1,33] = 29.32$, $p < .001$), though the effect of Clue Exposure failed to reach significance ($F[1,33] = 2.31$, $p = .138$). The important interaction between Word Type and Clue Exposure remained significant ($F[1,33] = 4.64$, $p < .05$), showing that the effect of analogy was greater when the clue word was exposed than when it was not (the adjusted means are reported in Table 3.2). In order to provide a direct measure of the size of the analogy effect, a score which described each subject's improvement between pre-and post-test on analogy words was derived. This was a difference score, calculated by subtracting the number of correct analogies made at pre-test from those made at post-test. These derived scores, which controlled for pre-test differences between the groups, were used in subsequent analyses of the analogy effect.

Table 3.2 Adjusted means - Number of words read at post-test in Experiment 1, taking account of differences at pre-test (Maximum = 20).

	Analogy Words	Control Words
Clue Exposed	7.47	3.04
Clue Not Exposed	5.70	2.97

To test whether the children's tendency to make analogies was related to reading skill, the derived scores were correlated with concurrent reading (raw) scores on a test of single word recognition (British Abilities Scales Word Reading Test, Elliott, Murray & Pearson, 1983), and on a measure of continuous (prose) reading (Neale Analysis of Reading Ability - Revised, Neale, 1989). The correlations were carried out separately for the children in the two exposure conditions. For the children who had the clue exposed at post-test, neither the BAS nor the Neale reading scores correlated significantly with the derived scores (0.25 and 0.16, respectively). However, for the children who did not have the clue exposed at post-test, the Neale reading scores significantly correlated with the derived scores ($r = 0.42$, d.f. $= 17$, $p < .05$). The correlation between the derived scores and performance on the BAS reading test fell short of statistical significance ($r = 0.37$, d.f. $= 17$, $p = .06$). The significance of the difference between the correlations for the two groups was tested using Fisher's z transformation statistic (Ferguson, 1981). The differences were non-significant for both reading measures ($z = 0.37$ for BAS reading and 0.77 for Neale reading).

3.2.3 Discussion

The results of this experiment replicate and extend those of Goswami (1986, 1991), and confirm that beginning readers as young as six years can use analogies when reading new words. Thus, analogy words were read more easily than control words following training with clue words on which the analogy words were based. Since different word lists produced no discernible effect on the subjects' ability to apply analogy principles, it would seem that children are not unduly sensitive to certain orthographic sequences above others.

A second question which this study addressed was the extent to which beginning readers use analogy spontaneously, that is, in the present context, when the clue word was not exposed at post-test. When the clue word was removed at post-test, the size of the analogy effect, though still significant, was substantially smaller than when the clue word was present. This was true even when differences in performance on the words at pre-test were controlled. These findings suggest that children analogise more effectively if they have the opportunity to refer back to the clue word. It might be that the visual similarity between the clue word and the new word alerts the child to the use of analogy. Alternatively, the clue word might remind the child of the pronunciation of the rime segment. This experiment cannot distinguish between these possibilities. However, it does throw doubt on the assumption that young children spontaneously use analogies with any degree of frequency. The extent to which they will do so depends upon their existing lexical knowledge. In beginner readers, lexical knowledge is necessarily limited and, consequently, it may not be easily retrieved for the purposes of reading by analogy. It is, therefore, proposed that while young readers have the potential to use analogies, this strategy will only come into force after they have had the opportunity to develop a sight vocabulary on which to base their analogical inferences.

This experiment did not formally attempt to address the issue of whether analogy skills are detectable in children with few, if any, reading skills. However, it was found that analogising correlated with a measure of reading in the children who were not exposed to the clue prompt at post-test. Thus, a measurable degree of reading skill may be necessary for analogising when it is not possible to refer to a clue. In the absence of clue words, children need to draw on other reading skills to aid word identification. For instance, they may use what limited phonic decoding skills they have to decode the initial part of the word and then use some of the letter cues in the final part to generate plausible candidate pronunciations. Any of these that match phonologically with pre-existing words in the child's spoken vocabulary might be tendered as acceptable responses. It is also of interest that of the 36 children in this study, 10 obtained 0 scores for all the words at both pre- and post-test i.e. no analogy effect was evident. All 10 were amongst the poorest readers and spellers in the sample, and three were effectively non-readers. On the other hand, all the children demonstrating the analogy effect had at least some reading and spelling skills; they registered scores that were above floor level on the BAS and Neale tests at the time of the study.

Thus, the present findings concur with those of Ehri and Robbins (1992) and of Bruck and Treiman (1992) who claimed that children need some decoding skill at the level of grapheme-to-phoneme correspondence to be sufficiently analytic about spellings to read words by analogy. The present results are at odds with Goswami's claim that analogy effects are demonstrable in non-readers. It would seem that a rudimentary reading vocabulary, and very possibly basic phonic decoding skills, need to be present before children can read by analogy, especially in the absence of a specific prompt.

3.3 Experiment 2

Goswami (1990) and Goswami and Mead (1992) have proposed that children's successful use of analogy is dependent on their pre-existing rhyming skills. In Goswami's (1990) study, children's performance on the Bradley "odd-word-out" rhyming test (Bradley, 1980) and on a test of phoneme deletion (adapted from Content, Morais, Alegria and Bertelsen, 1982) was related to their use of analogy in reading. When rhyming scores were entered, after scores on a test of receptive vocabulary (British Picture Vocabulary Scale, Dunn, Dunn & Whetton, 1982) in a two-step multiple regression, they accounted for 28 percent of the variance in analogising. Rhyming still accounted for 20 percent of the variance after controlling for the effects of phoneme deletion. Goswami has thus argued for a special link between rhyming ability and analogising. Further to this, Goswami and Bryant (1990) have hypothesised that rhyming skills promote children's awareness of the onset-rime distinction within words which may in turn influence their use of analogy in reading and spelling.

Goswami and Mead (1992) gave tests of reading, nonword reading, rhyme and alliteration (Bradley Test), syllable segmentation, deletion of initial or final consonants and complete phoneme segmentation to 44 six-year-olds. These skills were related to the children's ability to read beginning and end analogies. More analogy than control words were read correctly, and end analogies proved easier than beginning analogies. A series of fixed order three-step multiple regressions was carried out, relating the phonological variables to analogy, after controlling for the effects of reading ability and nonword reading. The rhyming measures significantly contributed to end analogising, while the ability to delete final consonants significantly related to beginning analogies. The ability to rhyme and to make end analogies was taken to reflect the children's awareness of onset-rime distinctions within words, whereas the ability to delete a final consonant and to make beginning analogies demanded the segmenting of words at boundaries other than those of onset and rime.

Experiment 2 focused on the children's phonological awareness before and during the beginning stages of learning to read, and its relation to their later use of analogy in reading. The phonological tests adopted tapped a wide range of skills. This experiment provided an opportunity to directly test Goswami's hypothesis that rhyming skills causally influence children's development of analogical processes in reading.

3.3.1 Method

3.3.1.1 Subjects

The 36 children who participated in the analogy experiment made up the sample for Experiment 2.

3.3.1.2 Design and Materials

The following tests of phonological awareness were administered: rhyme detection, rhyme production, phoneme identification, phoneme deletion and sound blending. These materials and their administration procedures are fully described in Chapter 2 (Method). The children's scores on the five phonological awareness tests were used as predictors in a set of Multiple Regression analyses, with performance in the analogy test i.e. the size of the analogy effect as the dependent variable. The children were also given two standardised tests of reading ability i.e. the British Abilities Scale Word Reading Test, BAS, (Elliott, Murray & Pearson, 1983), a test of single word reading, and the Neale Analysis of Reading Ability - Revised (Neale, 1989), a test of prose reading.

3.3.1.3 Procedure

The tests of rhyme detection, rhyme production, phoneme identification and phoneme deletion were given to the subjects when they were four, five and six years of age. The test sessions were separated by exactly one year. The test of sound blending and the standardised reading tests were given only at the five and six year test sessions.

3.3.2 Results

Table 3.3 shows the performance of the children on the tests of phonological awareness at ages four, five and six, together with their performance on the reading tests at ages five and six. As with the sample of 38 children (Chapter 2), a clear developmental progression between ages four and six years was evident for all measures.

Table 3.3 Performance on the tests of phonological awareness and reading at ages four, five and six (means and standard deviations of the raw scores).

Test	Age 4	Age 5	Age 6
Phonological Tests			
Rhyme Detection (/10)	5.5 (2.9)	8.1 (2.4)	8.4 (2.6)
Rhyme Production *	1.1 (1.7)	2.8 (3.2)	5.2 (4.4)
Phoneme Identification (/8)	2.1 (2.5)	3.4 (3.2)	6.4 (2.6)
Phoneme Deletion (/10)	0.4 (1.5)	2.4 (3.8)	5.2 (4.4)
Sound Blending (/32)		14.0 (5.5)	18.4 (5.9)
Reading Tests			
(number of words read correctly)			
BAS Reading	0	3.8 (5.6)	17.2 (15.1)
Neale Reading	0	9.2 (13.5)	57.2 (49.8)

* Number of rhyming words produced.

The scores on the phonological awareness tests at ages four, five and six were then correlated with the children's scores on standardised measures of reading at ages five and six (Table 3.4); logarithmically transformed scores were used where necessary (see Chapter 2 Results for rationale).

Table 3.4 Correlations between phonological skills at ages four, five and six and reading scores at ages five and six

	Age 5		Age 6	
	BAS	**Neale**	**BAS**	**Neale**
Age 4				
IQ	.45*	.32*	.45*	.47*
Rhyme Detection	.23	.19	.11	.14
Rhyme Production	.07	.06	-.08	-.07
Phoneme Identification	.28*	.30*	.37*	.35*
Phoneme Deletion	.06	.06	.11	.04
Age 5				
Rhyme Detection	.01	.02	-.02	-.02
Rhyme Production	.05	.07	.18	.10
Phoneme Identification	.40*	.41*	.42*	.42*
Phoneme Deletion	.44*	.44*	.53**	.57**
Sound Blending	.37*	.29*	.48*	.48**
Age 6				
Rhyme Detection			.43*	.40*
Rhyme Production			.45*	.47*
Phoneme Identification			.34*	.31*
Phoneme Deletion			.49**	.50**
Sound Blending			.54**	.52**

* Significant at the .05 level ** Significant at the .001 level.

The correlations between the phonological tests at age four and the reading and spelling measures at ages five and six showed that only phoneme identification correlated significantly with both reading measures at ages five and six.

Correlations between the phonological awareness scores at age five and the outcome measures in the same and the subsequent year showed that rhyming did not significantly correlate with reading at ages five and six, but phoneme identification, phoneme deletion and sound blending did. Finally, concurrent correlations for the phonological awareness scores and reading and spelling at age six showed that all the phonological awareness measures (including rhyming) correlated with reading and spelling in the same year.

To examine whether the children's phonological awareness was related to their use of analogies, scores on each of the phonological awareness measures at ages four, five and six were correlated with the derived scores describing the children's improvement on the analogy words from pre- to post-test. These correlations were conducted separately for the children in the clue and no clue exposure groups. The derived analogy score, which in principle ranged from 0 - 20, showed a mild positive skew and was thus subjected to the appropriate logarithmic transformation. In the group exposed to the clue at post-test, rhyme production at age five and rhyme detection at age six significantly correlated with the derived analogy scores ($r = 0.43$, d.f. = 17, $p < .05$; $r = 0.52$, d.f. = 17, $p < .05$, respectively). Phoneme deletion at age six also showed a significant correlation with analogy ($r = 0.41$, d.f. = 17, $p < .05$). None of the other phonological awareness measures correlated with analogising in this group. In the group not exposed to the clue at post-test, rhyme production at age six correlated very highly with analogy ability in the same year ($r = 0.57$, d.f. = 17, $p < .01$). No other significant correlations between phonological awareness and use of analogy were obtained for this group.

To investigate whether rhyming skills made a unique contribution to analogising, a series of fixed-order Multiple Regression analyses were carried. Transformed variables were used where appropriate. Although the ratio of subjects to independent variables meets the minimum requirement recommended by Tabachnick and Fidell (1989), it is not as favourable as it might be. The regression results are consequently interpreted with caution.

Since Verbal IQ and Neale reading had been found to significantly correlate with analogising for the no-clue-exposure group ($r = 0.52$, d.f. = 17, $p < .05$; $r = 0.42$, d.f. = 17, $p < .05$, respectively), it was important to enter these likely contributors to analogising ahead of the phonological tests in the first set of regressions. Thus, clue exposure type was entered as the first step, followed by Verbal IQ, then by Neale reading, and finally by each of the phonological awareness tests given at age six separately. Since rhyme production at age five had shown a significant correlation with analogising in the group exposed to the clue at post-test, this measure was also included in the multiple regressions (Table 3.5).

Table 3.5 Four-step multiple regressions relating analogies to phonological variables at ages five and six (dependent variable - derived analogy score)

	Change in R2	**F**	**p**
Step 1 (same for all)			
Clue Exposure Type	16.4	6.7	.05
Step 2 (same for all)			
Verbal IQ	4.4	4.3	ns
Step 3 (same for all)			
Neale Reading Score	2.6	3.3	ns
Step 4			
Rhyme Detection	4.3	3.0	ns
Rhyme Production	7.3	3.4	ns
Phoneme Identification	0	2.5	ns
Phoneme Deletion	2.4	2.4	ns
Sound Blending	1.0	2.5	ns
Rhyme Production (at age 5)	0	2.4	ns

The results of this analysis showed that clue exposure type significantly contributed to the variance in the use of analogy. However, neither Verbal IQ nor Neale reading made an independent contribution to analogising once clue exposure type had been accounted for. None of the phonological awareness measures significantly contributed to the use of analogy when entered as the last step in these analyses.

The second multiple regression analysis was carried out following the steps employed by Goswami (1990). In this analysis, clue exposure type was entered first, followed by Verbal IQ, then by each of the phonological tests (Table 3.6). Once again, clue exposure made a significant contribution to the use of analogy. Once this had been accounted for, Verbal IQ did not emerge as a significant contributor. However, in this analysis, concurrent rhyme production made a significant and independent contribution to analogising when entered as the final step, though performance on the other phonological measures did not.

Table 3.6 Three-step multiple regressions relating analogies to phonological variables at ages five and six (dependent variable - derived analogy score)

	Change in R2	**F**	**p**
Step 1 (same for all)			
Clue Exposure Type	16.4	6.7	.05
Step 2 (same for all)			
Verbal IQ	4.4	4.3	ns
Step 3			
Rhyme Detection	5.4	3.8	ns
Rhyme Production	9.7	4.7	.05
Phoneme Identification	1.0	2.8	ns
Phoneme Deletion	4.4	3.6	ns
Sound Blending	0	2.8	ns
Rhyme Production (at age 5)	0	2.9	ns

Since neither Verbal IQ nor Neale reading accounted for a significant amount of variance in analogising, a two-step multiple regression was justified, entering clue exposure type ahead of each of the phonological measures (Table 3.7). In these analyses, clue exposure, concurrent rhyme detection and rhyme production emerged as significant.

Table 3.7 Two-step multiple regressions relating analogies to phonological variables at ages five and six (dependent variable - derived analogy score)

	Change in R2	F	p
Step 1 (same for all)			
Clue Exposure Type	16.4	6.7	.05
Step 2			
Rhyme Detection	9.7	5.8	.05
Rhyme Production	14.1	7.2	.05
Phoneme Identification	0.1	3.4	ns
Phoneme Deletion	8.0	5.4	ns
Sound Blending	1.2	3.5	ns
Rhyme Production (at age 5)	2.0	3.8	ns

Finally, the original multiple regression analyses were repeated separately for the two clue exposure type groups. Verbal IQ was entered first, followed by reading scores, and finally by each of the phonological tests that had shown a significant correlation with analogising. For the clue exposure group, the BAS reading score was used in preference to the Neale because of its higher correlation with analogising in this group. Neither Verbal IQ nor BAS reading ability made a significant contribution to analogising ($F[1,16] = 0.12$, and $F[2,15] = 0.99$, respectively). Rhyme production at age five did not account for a significant amount of variance when entered as the last step in the multiple regression ($F[3,14] = 1.85$). However, rhyme detection at age six significantly contributed to analogising in this group ($F[3,14] = 2.87$, $p < .05$). None of the other phonological tests made a significant contribution. For the group not exposed to the clue at post-test, neither Verbal IQ nor Neale reading ability accounted for a significant amount of variance in the derived analogy scores ($F[1,16] = 1.97$, and ($F[2,15] = 1.04$, respectively). Of the phonological tests, only rhyme production at age six made a significant contribution to the analogy effect when entered as the final step after Verbal IQ and Neale reading ($F[3,14] = 2.51$, $p < .05$).

In all of the multiple regression analyses, the majority of the variance was accounted for by clue exposure type (some 16 percent of the variance in analogising). In contrast, Verbal IQ accounted for only 4.4 percent of the variance, and Neale reading ability for only 2.6 percent of the variance in the three- and four-step analyses. Of relevance to the "rhyme as a special link hypothesis", rhyme production accounted for a significant 14 percent of the variance after controlling for clue exposure type in the two-step analysis (and a still significant 9.7 percent in the three-step analysis). For the group not exposed to the clue at post-test, concurrent rhyme production contributed a significant 22 percent of the variance in analogising after controlling for Verbal IQ and reading skill, and for the group exposed to the clue at post-test, concurrent rhyme detection accounted for a significant 26 percent of the variance.

3.3.3 Discussion

The results of Experiment 2 confirmed the findings of Goswami (1990) and Goswami and Mead (1992) in demonstrating a special link between rhyming and children's use of analogy. Simple correlations showed that rhyme production at age five, together with rhyme detection and phoneme deletion at age six, correlated significantly with analogising in the group exposed to the clue word at post-test. Concurrent rhyme production correlated with the analogy effect in the group not exposed to the clue at post-test. The phoneme deletion task employed in this study required the children to split the word into its onset and rime, and then to delete the onset. It could, therefore, be viewed as a test of onset-rime awareness. Indeed, in the Principal Components Analyses conducted in

Chapter 2, phoneme deletion correlated 0.60 with the Rhyming Factor in Year 3 of the longitudinal study. Similarly, its correlation with the analogy effect might be explained by the fact that at least some of the children responded to the phoneme deletion test as a rhyming or onset-rime task. Goswami (1990) described a near significant contribution of initial consonant deletion to analogy in her three-step multiple regression ($p = .07$). Also, Goswami and Mead (1992) found that initial consonant deletion made a significant contribution to end analogising after controlling for reading ability.

In the multiple regression analyses, a large proportion of the variance was attributable to whether or not the clue was exposed at post-test. However, when the effect of clue exposure was controlled, concurrent rhyme production made a significant contribution to analogising in both the two- and three-step multiple regressions. Both concurrent rhyme detection and production scores made a significant contribution to analogising in the two-step multiple regression (after entering clue exposure type as the first step).

In the group that had the clue exposed at post-test, concurrent rhyme detection contributed 26 percent to the variance in analogising when entered as the last step in a multiple regression analysis. Rhyme production in the same year as the experiment contributed 22 percent to the variance in analogising for the group that did not have the clue exposed at post-test. Neither rhyme production at age five nor concurrent phoneme deletion emerged as significant contributors to the analogy effect in any of the Multiple Regression analyses.

These analyses provide evidence confirming the important role of rhyming in the development of analogical processes in reading. However, the strong causal connection, hypothesised by Goswami (1990) and Goswami and Mead (1992), is not borne out by the present findings. Rhyming skills measured at ages four and five did not significantly contribute to analogising at age six. Rather, it was rhyming ability in the same year that seemed to be the most important factor.

3.4 General Discussion

The results of Experiments 1 and 2 have replicated Goswami's finding that very young children can use analogies in reading. Experiment 1 confirmed that children, as young as six, receiving training on clue words were able to transfer this knowledge to new words having rimes analogous to the words on which they were trained. However, the analogy effect was substantially reduced when the children did not have access to the clue word during the post-test phase. It is proposed that Goswami underestimated the role of the clue word as a referent during the post-test. Without this reminder of the orthographic structure of the clue word, children are less able to transfer knowledge of the pronunciation of the shared letter sequence to new words.

The present study showed that the analogy effect correlated significantly with reading performance for the children who were not exposed to the clue at post-test. However, the difference in correlations between the two clue exposure groups did not attain significance, perhaps not surprising in view of the small sample size. While recognising that these results need to be replicated in a larger scale study, the following tentative explanation is proposed. For the children not exposed to the clue at post-test, training on the clue word may have primed their pre-existing lexical knowledge of words that were orthographically similar. Such knowledge would have been more easily retrieved during reading at post-test. However, for the children who had the clue exposed at post-test, the influence of pre-existing lexical knowledge primed by training would have assumed far less importance, since they always had the clue available for reference.

The analogy experiment took place in the final year of the longitudinal study reported in Chapter 2. As already discussed, two independent factors, a rhyming and a segmentation factor, were found to exert differential influences over early reading and spelling development. Segmentation ability, in interaction with letter knowledge, fuelled progress in reading, and in particular spelling, during the first year at school. Rhyming did not contribute to reading or spelling performance in the first year, but did have a significant influence, alongside segmentation, on spelling progress in the following year. In contrast, neither segmentation nor rhyming skills contributed to reading ability in the second year; the major contributors were in fact reading vocabulary from the previous year, together with concurrent letter knowledge. Taken together with the present results, these findings favour an interpretation of children, first using knowledge of sound-to-letter relationships to read and later, with increasing awareness of orthographic regularities and of rhyme, using analogies. Spelling, on the other hand, remains phonological, with both segmentation and rhyming exerting a significant influence over its development.

3.5 Conclusions

Both the present analogy experiment and the broader longitudinal study, within which it was embedded, offer only partial support for the model proposed by Goswami and Bryant (1990). Goswami and Bryant hypothesised that rhyming concentrates children's attention on onset-rime boundaries of words. Thus, awareness that "cat" can be segmented into "c-at" promotes the application of analogical principles to words that share the same rime e.g. "rat, sat". Later, children's phonological segmentation abilities are refined and promote their awareness of phoneme-to-grapheme relationships, enabling them to "sound out" words they are asked to read and spell e.g "cat" is segmented into "c-a-t". In the present longitudinal study, phonemic segmentation exerted the initial effect on reading and spelling during the first year of school, while rhyme, which had a special bearing on the use of analogies, did not emerge until the following year. It was confirmed that rhyming in the same year was a good predictor of the skill with which children use analogies (c.f. Goswami, 1990). However, it was found that, when children could not refer to the taught "clue" word, their use of analogies was also related to their reading skill. These results suggest that children only begin to use analogies after they have started reading, and that it is at this point that rhyming skill becomes relevant.

Chapter 4

Language Development in Children with Lateralised Brain Lesions

While there has been extensive research on the causal factors underlying early literacy development in normal children and those with developmental reading and writing disorders, there is a dearth of information on children with brain injury. The second half of this thesis focuses on the development of language, and in particular, the educational attainments of young children with unilateral brain lesions. The aim is, first, to evaluate the effects of lateralised cerebral damage on children's development of literacy and related skills. Second, because the study is longitudinal in design, it will be possible to address issues relating to causal influences in early reading, rate of development and change in cognitive presentation over time.

Historically, there have been three main reasons for studying the learning patterns of children with brain lesions. First, the need for neuropsychological evaluation for the purposes of clinical diagnosis and patient management. Second, because the deficits of such children and their compensatory processes are an important source of information for testing the validity of theories relating underlying pathology to specific aspects of cognitive function. Finally, the study of patients whose injury has been incurred pre- or peri-natally provides an opportunity to investigate the developing brains' capacity for functional reorganisation and sparing of function. Two groups of subjects that have often been studied, with a view to addressing these issues, are hemiplegic and hemidecorticated (or hemispherectomized) individuals. The defining features of these neurological disorders are described in the following section.

4.1 Hemiplegia, Hemidecortication and Functional Reorganisation

Cerebral palsy is defined by Aicardi (1992) as "a persistent disorder of movement and posture caused by non-progressive pathological processes of the immature brain" (p.

330). Its incidence is two per 1,000 births, of which congenital hemiplegia accounts for approximately one-third (Brett, 1983). It is usually attributed to a thrombotic, vasospasmic or embolic episode in the middle cerebral and/or carotid artery between the end of the second trimester of pregnancy and the early post-natal period (Aicardi, 1992). The adult equivalent is a stroke or cerebrovascular accident in the territory of the middle cerebral artery. Unilateral paresis and spasticity are characteristic features of congenital hemiplegia and are typically diagnosed during the first year of life (Aicardi, 1992). Epilepsy is a major complication, with between 25 to 40 percent of hemiplegics going on to develop seizures (Aicardi, 1992). Wiklund and Uvebrant (1991), in a population study of 151 children with pre- or peri-natal hemiplegia, found that there were slightly more boys than girls affected, and that right hemisphere damage was predominant among pre-term babies while left hemisphere damage occurred more often in full-term babies. Computerised Tomography (CT) scans failed to establish a statistical correlation between the severity of motor impairment and the size of the lesion. Nor did the severity of epilepsy, which affected 24 percent of the sample, correlate with the location or extent of the lesion. Hemiplegia may also be acquired after the peri-natal period, as a result of head injury, tumours, cerebrovascular accidents or specific illnesses such as encephalitis (Aicardi, 1992).

Hemispherectomy, which is more appropriately referred to as hemidecortication, usually involves the surgical removal of most of one cerebral hemisphere, including the insular cortex and various portions of the basal ganglia (Goodman, 1986). It is used as a treatment for severe and intractable epilepsy, often accompanied by behaviour disorder, and in which there is congenital, peri-natal or acquired pathology of one cerebral hemisphere (Wilson, 1970). Hemidecortication is highly effective in either eliminating, or at least substantially reducing, seizure incidence; in the case of congenital or early onset hemiplegia and seizures, there may be surprisingly little cost to the patient's neurological or gross cognitive status (see Vargha-Khadem and Polkey, 1992, for a review).

It is important to clearly distinguish between the features of hemiplegic and hemidecorticated patients if one is to fully appreciate the types and level of information about function these subjects provide. Hemiplegic patients have one damaged and one (assumed) functional hemisphere; seizures are present in a sizeable minority of cases. Hemidecorticates have one (again assumed) functional hemisphere, while the other is "absent"; seizures, at least prior to surgery, are a feature of all of these patients. In reality, the remaining hemisphere of hemidecorticated patients is not truly intact; the functions it serves are likely to have been affected both by the seizure disorder and by the forced reorganisation consequent on the functional failure of the diseased hemisphere.

Children having pre-natal or peri-natal hemiplegia have proved an invaluable source of information about the relative plasticity of the developing brain and its capacity for functional reorganisation. Plasticity refers to the extent to which the immature brain is capable of compensating for damage to specific areas. The process through which remaining intact regions within the brain take over the functions of the damaged portion is known as functional reorganisation. Cases of hemidecortication are powerful magnifiers of laterality effects, and have played an especially important role in assessing the language capabilities of the right cerebral hemisphere. As Zaidel (1980) states "This is not because they necessarily represent normal function in each hemisphere but rather they illustrate limit cases of independent hemispheric processing against which outstanding theoretical hypotheses and methodological questions can be resolved, and new ones generated" (p. 56).

4.2 Cerebral Lateralisation in the Normal Brain

It has been well known for many years that there is asymmetric specialisation of the cerebral hemispheres in man. Passingham (1982) describes the two specialisations relating to language which are unique to the human brain. The first, cerebral dominance, refers to the greater role played by the left than the right hemisphere in controlling speech. The second is the existence of "speech areas" in the neocortex (Broca's area in the frontal neocortex and Wernicke's area in the temporal and parietal lobes) which direct the comprehension and production of speech. While the left hemisphere is predominant in the language domain, the right hemisphere predominates in visuospatial functions. Kolb and Whishaw (1990) have, however, pointed out that this apparent double dissociation of function is not straightforward, for the following three reasons. First, lateralisation can be affected by factors such as handedness and sex, such that some left-handers and females have less marked functional asymmetry than right-handers and males. Second, lateralisation is relative, rather than absolute, because both hemispheres play a role in nearly every behaviour; consequently, although the left hemisphere is especially important for the production of language, the right hemisphere also demonstrates some language capabilities. Finally, asymmetry is not uniquely human, since certain songbirds, cats, rats and monkeys have anatomically and functionally asymmetric brains.

Passingham (1982) has summarised the anatomical evidence for cerebral asymmetry within the human brain. The planum temporale is larger in the left than the right hemisphere, the left Sylvian fissure is longer than the right, and the back of this fissure tends to run lower on the left than the right side. Because the anatomical asymmetries of the left hemisphere centre primarily on language areas, it is tempting to speculate that they evolved to subserve the production of language. However, as Passingham (1982) has pointed out, we need to be cautious about linking anatomical asymmetry with language function because, for instance, asymmetries in the length of the Sylvian fissure have been found not only in humans but also in apes. The picture is further complicated by the observation of asymmetries that favour the right hemisphere. These are summarised by Kolb and Wishaw (1990), and include a longer posterior pole on the right than the left, a larger area of convexity of the right frontal operculum and a larger right medial geniculate nucleus; these authors conclude that "these asymmetries presumably reflect some as yet unspecified gross difference in cerebral organisation" (p. 350).

Neurophysiological measures, such as Electroencephalograms (EEGs) and Cortical Evoked Responses (CERs), have shown some positive evidence of asymmetric recordings during behavioural tasks (see Kolb and Whishaw, 1990, for a review). For instance, Molfese and Molfese (1980) demonstrated, using CERs, that the left hemisphere is differentially sensitive to speech sounds. Although the search for neurophysiological correlates of asymmetric specialisation has been fraught with serious methodological inadequacies (Kolb and Whishaw, 1990), the development of new functional imaging techniques such as Positron Emission Tomography (PET) seems especially promising. Non-invasive behavioural indices of asymmetric specialisation that have been employed with normal humans include tachistoscopic, dichotic listening and dichaptic techniques. Tachistoscope studies, in which visual information can be presented to each visual field independently, have demonstrated a right-field advantage for verbal material and a left-field advantage for visuospatial stimuli (Mishkin and Forgays, 1952). Similarly, dichotic listening studies have reported a right-ear advantage for speech sounds and a left-ear advantage for melodies (Kimura, 1963). Finally, dichaptic studies have demonstrated a left-hand superiority for the tactile recognition of unseen complex shapes (Witelson and Pallie, 1973). Since the visual, sensorimotor and auditory systems in man are characterised by predominantly crossed connections, these findings are consistent with verbal/speech material being processed in the left hemisphere and visuospatial/melodic/tactile stimuli being processed in the right hemisphere.

However, it should be noted that the findings of dichotic listening studies do not correlate perfectly with those from studies employing invasive measures of cerebral asymmetry (such as sodium Amytal, see Section 4.3). Dichotic studies show a right-ear bias for about 80 percent of normal right-handed subjects (see Hiscock and Decter, 1988, for a review), while sodium Amytal studies have demonstrated that language is represented in the left hemisphere in over 95 percent of right-handed patients without evidence of early left cerebral damage (Rasmussen and Milner, 1977). Which subject population and which technique provide the more accurate estimate of speech lateralisation is questionable. Kolb and Wishaw (1990) discuss some of the problems associated with non-invasive and, therefore, indirect techniques. First, it has been observed that tachistoscopic and dichotic measures of laterality are not as highly concordant as one might expect. Second, there is the finding that repeated testing of subjects on dichotic listening tests does not always produce consistent results, although the general pattern of right-ear advantage in the majority of subjects is replicated across studies. Blumstein, Goodglass and Tartter (1975) showed that the test-retest reliability of dichotic listening, even over short test-retest intervals, is rarely more than 0.70. Twenty nine percent of the subjects in their sample reversed their ear advantage upon retesting. This reversal effect may be even more pronounced in children. Bakker, Hoefkens and Van der Vlught (1979) found that of children showing a right-ear advantage in kindergarten, 43 percent reversed their ear advantage once or even twice in the following three years. Of the children who showed an initial left-ear advantage, 77 percent subsequently changed their ear advantage at least once.

4.3 Brain Injury, Cerebral Lateralisation and Recovery of Function in Adults

Cerebral asymmetry was first established through the study of patients who had neurological disease lateralised to one hemisphere (Passingham, 1982). This group of patients continues to provide valuable information about the issues of cerebral lateralisation, especially of language. The concept that provides the most powerful demonstration of lateralisation is that of **double dissociation** (Teuber, 1955). It has been consistently demonstrated that, in right-handed adult patients, lesions of the left hemisphere produce deficits in language functions, while leaving non-verbal abilities unimpaired (see Kolb and Wishaw, 1990, for a review). Conversely, lesions of the right hemisphere result in the impairment of non-verbal abilities; this has been demonstrated in most sensory domains including the auditory (e.g. discriminating tonal patterns), tactile (e.g. discriminating complex shapes) and visual (e.g. discriminating visuospatial patterns) domains (see Kolb and Wishaw, 1990). However, in right hemisphere insult patients, verbal abilities are spared.

There is also behavioural evidence in support of cerebral lateralisation that comes from neurosurgical patients undergoing clinical procedures. Stimulation of the left hemisphere during neurosurgery can block the ability to speak in the conscious patient, while stimulation of the right hemisphere seldom does so (see Kolb and Wishaw, 1990, for a review). The sodium Amytal test, which involves temporary inactivation of one hemisphere at a time, permits the study of the gross language and memory capabilities of each hemisphere without the contribution of the other (Wada and Rasmussen, 1960). Rasmussen and Milner (1977) have provided data on 262 patients, without evidence of early left cerebral damage, who underwent the sodium Amytal test to determine cerebral lateralisation of speech. Of the right-handers, 96 percent had left hemisphere speech representation, while the remaining four percent had right hemisphere speech representation. Of the left-handers, 70 percent had left hemisphere speech representation, 15 percent had speech lateralised to the right hemisphere, while the remaining 15 percent had bilateral speech representation. The preference for left hemisphere lateralisation of language may be altered if an early left hemisphere injury occurs. One hundred and thirty four patients with early left hemisphere lesions were subjected to the sodium Amytal procedure (Rasmussen and Milner, 1977). Of the 42 who were right-handed, 82 percent had left hemisphere speech representation. Of the 92 non-right-handed patients, 53 percent had speech represented in the right hemisphere, 28 percent had speech represented in the left hemisphere, while the remaining 19 percent had bilateral speech representation. A shift towards right hemisphere dominance after left-sided damage is most likely if the lesion includes the primary speech zones (Rasmussen and Milner, 1977).

Ratcliff, Dila, Taylor and Milner (1980) have attempted to relate hemispheric representation of speech and morphological asymmetries of the cerebral hemispheres to Annett's model of hand preference (Annett, 1972, 1976). This model states that hand preference is mainly determined by a genetic "right-shift factor" which is present in the majority of the population, biasing its carriers in favour of right-hand superiority. Ratcliff et al. reported that the usual asymmetry of the post-Sylvian branches of the middle cerebral artery is found in patients with left hemisphere speech representation, but is significantly reduced in patients with atypical cerebral dominance for speech. These authors propose that the majority of the population, in whom the right-shift factor is present, will be biased in favour of right-handedness, left-hemispheric speech representation and morphological asymmetry of the cerebral hemispheres. The minority, lacking the shift factor, will be unbiased on all three variables, and consequently their handedness, hemispheric speech representation and morphological asymmetry will be randomly determined.

In spite of the specialisation and lateralisation features of brain function in man, there is substantial evidence for striking degrees of functional recovery following even severe brain damage (Teuber, 1975). In general, the recovery of sensory and motor functions is usually gradual and orderly, while the recovery of cognitive functions may be more complex and neither as orderly nor as predictable (Kolb and Wishaw, 1990). These authors go on to discuss three general principles relating to the effects of brain injury in adults. First, the recovery of complex cognitive behaviour is likely to involve a great deal of behavioural compensation, including modification and restructuring of the external environment and the use of internal cognitive strategies. Second, recovery tends to be greater after traumatic damage, for instance head injury as opposed to a cerebrovascular accident. Strokes probably damage large areas of the brain thus removing entire functional areas, while traumatic injuries are usually more diffuse and spare many areas. Finally, recovery is unlikely for specific functions controlled by localised brain areas if all the relevant area is removed. For instance, after left dorsolateral prefrontal lesions there is usually no recovery in card sorting ability, a function specific to that region of the frontal lobe in man (Milner, 1963).

Finger and Stein (1982) reviewed outcome studies from which they were able to draw a series of principles relating to mechanisms of recovery from brain injury. First, there may be contralateral or ipsilateral transfer of function. In the former, the transfer is typically from a damaged area of one hemisphere to the corresponding area on the other side e.g. from damaged left temporal cortex to intact right temporal cortex. In ipsilateral transfer, an undamaged adjoining area of the same hemisphere takes over the function of the damaged area e.g. from damaged left precentral cortex to intact left postcentral cortex. Second, lost abilities may be regained by restitution, in which the original strategy for achieving a particular end is fully or partly recovered (e.g. recovery of right-handed skill after a right-sided stroke), or by substitution in which an alternative strategy is used to achieve the same end (e.g. learning to use the left hand instead). Finally, it is generally the case that the earlier the brain damage occurs, the better the outcome. The developing brain appears to possess a greater capacity for reorganisation (either through contralateral or ipsilateral transfer) than does the adult brain.

It is important to distinguish between restitution (or recovery) and reorganisation of function. Recovery is a concept most usually applicable to patients incurring a neurological injury after a given skill has been developed; it implies that an established skill, lost as a result of a neurological insult, has been fully or partially regained. Reorganisation is a term that is perhaps more appropriate to cases of injury occurring early in development. The implication is that remaining intact regions of the brain gradually come to take over the functions of the damaged areas, thus permitting skills specific to the damaged region to develop, though not necessarily as they might normally have done; such a concept needs to take into account the level of development of a given skill or function at the time of injury.

4.4 Equipotentiality - Theory and Historical Overview

There is little dispute over the question of cerebral lateralisation and specialisation of function in adults, but the evidence relating to these issues in children is both equivocal and controversial. In 1967, Lenneberg suggested that the two hemispheres are equipotential for language function at birth and that they become progressively specialised during the course of childhood. It follows that either hemisphere has the ability to subserve speech and language functions in the face of early unilateral damage. The classic study he quoted to support this view was that of Basser (1962), who had the opportunity to study intensively 35 cases of hemidecortication. It was found that in the majority of cases, irrespective of the side of injury and subsequent surgical removal, speech was unchanged; in a few an observable improvement occurred, and in only one case did dysphasia develop. Basser concluded that speech could be developed and maintained in the remaining hemisphere and that in this respect the left and right hemispheres were equipotential.

In the late 1970s and early 1980s, there was increasing evidence that the anatomical and functional asymmetries reported in adults could be replicated in neonates, infants and even foetuses.

Witelson and Pallie (1973) and Wada, Clarke and Hamm (1975) carried out post-mortem anatomical studies of foetuses, and were able to show that the planum temporale is generally larger in the left than the right hemisphere. In the Wada et al. study, 100 brains were analysed. The mean age was 48 weeks, including the gestational period. On the average, the left temporal plane was 77 percent larger than the right-temporal plane. Fifty six percent of the brains had left side larger than right side, 12 percent had right side larger than left side, and 32 percent had equal measurements on the left and right.

Electrophysiological studies also pointed to there being asymmetries in the infant brain. Molfese and Molfese (1980) recorded CERs from both hemispheres in neonates who were subjected to speech sounds. They found responses of greater amplitude, presumably reflecting greater involvement in the processing of sounds, in the left hemisphere of the majority of infants. When the infants were presented with non-speech sounds (e.g. a noise burst or a piano chord), they showed evoked responses of greater amplitude in the right hemisphere.

Finally, there are behavioural indices of functional asymmetry that may be applied to neonates and infants. Turkowitz (1977) demonstrated lateral preference in neonates by observing left and right head turning behaviour. Infants just a few days old show a marked preference for right-side head turns. There is some suggestion that this preference may be related to hand preference in later life. Viviani, Turkowitz and Karp (1978) reported a statistically significant correlation between head turning in infancy and lateral preference at age seven.

The evidence from dichotic listening studies has been rather more equivocal. Entus (1977) adopted the dichotic listening paradigm and coupled it with the "non-nutritive sucking response". Entus reported greater recovery of the sucking response when a novel consonant-vowel pair was presented to the right rather than the left ear. Conversely, she reported greater recovery of the sucking response when a musical note was presented to the left rather than the right ear. This evidence suggested that there was a lateralised brain preference - left for phonemes, right for musical notes - as early as 22 days after birth. However, Vargha-Khadem and Corballis (1979) were unable to replicate these results. They repeated the study using a comparable procedure, except for a modification which eliminated a source of experimenter bias that was present in the Entus study (the latter study was not entirely experimenter-blind). Vargha-Khadem and Corballis failed to obtain a lateralised preference as Entus had done. They concluded that there may be "no appreciable difference in the capacities of the left and right hemispheres to discriminate speech sounds at this age" (p. 8).

With the accumulating evidence favouring anatomical and functional asymmetry even in very young children, increasing doubt was cast on the equipotentiality hypothesis. Whether this doubt was justified is in itself debatable since the link between anatomical/functional asymmetry and the presence of hemispheric specialisation for language may be regarded as somewhat tenuous (Section 4.2). At any rate, a swing to the reverse i.e. anti-equipotentiality position began to take place. This was marshalled on the neuropsychological front in the 1970s and '80s by a series of studies of two separate populations of clinical patients. These were children with pre-/peri-natal or acquired unilateral cerebral injury (McFie, 1961; Alajouanne and Lhermitte, 1965; Woods and Teuber, 1973; Annett, 1973; Hecaen, 1976; Woods and Carey, 1979; Woods and Teuber, 1978; Woods, 1980; Rankin, Aram and Horowitz, 1981; Aram, Ekelman, Rose and Whitaker, 1985; Vargha-Khadem, O'Gorman and Watters, 1985; Aram, Ekelman and Whitaker, 1986; Aram and Ekelman, 1986; Aram and Ekelman, 1987; Riva and Cazzaniga, 1986; Aram, Ekelman and Whitaker, 1987; Aram and Ekelman, 1988; Aram, Myers and Ekelman, 1990; Eisele, 1992), and those individuals who had undergone hemidecortication for the treatment of intractable epilepsy (Dennis and Kohn, 1975; Dennis and Whitaker, 1976; Dennis, 1980; Dennis, Lovett and Weigel-Crump, 1981; and Lovett, Dennis and Newman, 1986). In general, these studies reported that, while early left-hemisphere-damaged patients may escape gross language impairment, nonetheless subtle and specific language deficits remain. These findings supported the view that the left hemisphere retains specialisation for language that the right hemisphere cannot override.

Research conducted up to the mid- to late-1980s tended to treat the opposition between equipotentiality and early specialisation as a yes/no question i.e. the two cerebral hemispheres are or are not equipotential for language. Satz, Strauss and Whitaker (1990) have argued instead for a continuum, with equipotentiality and early specialisation occupying the two poles. Thus, there may be a strong initial bias towards left hemisphere specialisation for language. However, it appears that the non-dominant hemisphere can acquire and mediate language successfully under certain conditions. Indeed, the capacity of the non-dominant hemisphere to process language may be affected and modified by a range of factors, such as size and location of lesion, age at onset of injury and the presence of seizures. Few of the studies favouring the anti-equipotentiality stance took account of, or attempted to control for, these factors. In addition, it became apparent that many of these studies suffered severe methodological flaws, a number of which were highlighted in two critical review papers by Dorothy Bishop (Bishop, 1983, 1987); see Section 4.6 for a full discussion.

Recent studies have overcome many of the methodological inadequacies of the earlier work, and have also controlled (or accounted) for factors that may influence the capacity for functional reorganisation and behavioural outcome e.g. presence of seizures, age at onset of lesion (see Section 4.7). The result has been a reconsideration of the issues surrounding equipotentiality. Indeed, recent evidence has once again tended to favour the equipotentiality end of the continuum, but with increasing recognition that the extent of successful reorganisation may be modified by these factors (Levine, Huttenlocher, Banich and Duda, 1987; Ogden, 1988; Ogden, 1989; Banich, Levine, Kim and Huttonlocher, 1990; Sussova, Seidl and Faber, 1990; Vargha-Khadem, Isaacs, Papaleloudi, Polkey and Wilson, 1991; Vargha-Khadem, Isaacs, Van der Werf, Robb and Wilson, 1992).

4.5 Evidence from Studies of Childhood Unilateral Brain Injury and of Hemidecortication Supporting the Anti-Equipotentiality Position

The first study of the effects of unilateral brain damage sustained during childhood was conducted by John McFie (1961) in his study of 40 patients who had acquired a hemiplegia after the age of one year. Although the right- and left-lesioned groups did not differ with respect to their overall IQ scores, nonetheless patterns of deficit similar to that seen in adults were reported; patients with right hemisphere lesions tended to show impairment on visuospatial tasks, while patients with left hemisphere lesions were more likely to show impairment on language and verbal memory tasks.

Two other early studies (Alajouanne and Lhermitte, 1965; and Hacaen, 1976) investigated the recovery from aphasia in children with acquired left hemisphere lesions. Nearly all of the children in both studies displayed marked disorders of speech and of written language skills following injury. On follow-up (six months in the Alajouanne and Lhermitte study, up to two years in the Hacaen study), most of the children showed good apparent clinical recovery, although some subtle language deficits persisted.

Woods and Teuber (1973), Woods and Teuber (1978) and Woods (1980) reported evidence to show that aphasic speech disturbance following post-natally acquired unilateral lesions is more likely in cases of left- than right-sided damage in childhood and that, furthermore, this effect is especially prominent if the lesion is incurred after one year of age. Woods and his associates also found that the IQs of their congenital hemiplegic subjects tended to be depressed but not outside the normal range, and that laterality effects of the sort seen in adult patients with unilateral damage were uncommon (Warrington, James and Maciejewski, 1986). However, mild and subtle language deficits persisted even in the case of very early (peri-natal and early infancy) left hemisphere lesions (Woods and Carey, 1979). With lesions occurring after the age of one year, there was a restricted effect of right hemisphere injury on Performance IQ, but not of left hemisphere injury on Verbal IQ (Woods, 1980). Woods and his colleagues claimed support for the anti-equipotentiality position. They proposed that the left hemisphere has the leading role in speech development from the outset. The right hemisphere has only the potential for language which diminishes during childhood as it becomes increasingly committed to other functions.

Aram and her colleagues have made extensive studies of the language and scholastic achievements of children having unilateral brain lesions acquired in early childhood. In all the studies, the majority of children had incurred brain injury in the form of a cerebrovascular accident sustained after cardiac catheterisation or surgery for congenital heart disorders. The second most likely cause of the hemiplegia was a pre- or peri-natal insult. Smaller numbers of children had unilateral injuries arising from arteriovenous malformation or from meningitis. The age at onset of injury varied from one study to another. However, most of the studies employed a mix of pre-/peri-natal and acquired cases; in some instances, the age at onset was as late as 14 years. Age at testing also varied a great deal, but in many studies some subjects were tested as young as five years and others as old as 17 years. The interval between age at onset and at testing ranged from about two years up to 10 years. Apart from the early studies, sample sizes were comparatively large, given the clinical nature of the population. The hemiplegic children were carefully matched with control children who suffered from congenital heart disorders, on age, sex and race. The matching procedure yielded two control groups, one for the right hemisphere cases and one for the left cases. Thus all the studies compared each hemiplegic group with its own control group, but never the left-hemisphere- versus the right-hemisphere-injured groups. The extent and laterality of the lesion was confirmed by CT scan, with cases of bilateral involvement or ongoing seizures being excluded from the hemiplegic sample.

There have been two studies by Aram and her colleagues that have concentrated on IQ profiles. Aram, Ekelman, Rose and Whitaker (1985) compared eight left-lesioned and eight right-lesioned subjects, together with matched controls, on Wechsler IQ. Age at onset of injury varied from one month to seven years. The lesioned children were reported to have lower IQs than their controls but were still considered to be within normal limits. The right-lesioned group was depressed in Performance, Verbal and Full Scale IQs while the left-lesioned group was depressed on the Performance and Full Scale (but not Verbal) IQs, relative to their own control groups. No Verbal-Performance discrepancy was evident for either lesioned group. The failure to observe a laterality effect was also noted in the larger scale study by Aram and Ekelman (1986). These authors explored the IQ test profiles of 18 left- and 13 right-lesioned patients, some of whom had pre-/peri-natal injuries, while others had acquired their injuries in later childhood (as late as 10-14 years in some instances). The lesioned children scored within normal limits on the Wechsler Intelligence Scale for Children - Revised (WISC-R), although the right-lesioned group scored significantly below its matched control group.

The focus of much of Aram's work has been that of studying specific language characteristics in children with unilateral lesions. Rankin, Aram and Horowitz (1981) found that three children with left-sided injury performed less well on measures of language (e.g. on tests of syntax, vocabulary, naming fluency and phoneme discrimination) than three children with right-sided injury. Aram, Ekelman and Whitaker (1986) studied the spontaneous language samples of eight left- and eight right-lesioned patients. The left-lesioned subjects performed more poorly than their controls on most measures of simple and complex sentence structure. In contrast, the right-lesioned subjects performed similarly to their controls on all measures. Aram, Ekelman and Whitaker (1987) administered a lexical retrieval task to 19 left- and 13 right-lesioned children (again a mixed group of pre-/peri-natal and acquired cases). The left-lesioned group scored below their matched controls across a range of lexical access conditions and semantic categories, while the right-lesioned group performed similarly to their controls. Aram and Ekelman (1987) gave the Revised Token Test to 17 left- and 11 right-lesioned children, presumably a sub-group of the sample studied by Aram et al. (1987) . While the overall results showed no differences between right- and left-lesioned groups, there was nonetheless a substantial degree of subtest variation. The authors proposed that poorer performance by the left-lesioned group on certain subtests might be attributed to their having problems coping with the memory demands of the Token Test. In contrast, the right-lesioned group showed more attentional limitations and impulsive behaviour.

Aram, Myers and Ekelman (1990) studied the speech fluency patterns of 30 children with unilateral lesions of pre-/perinatal or acquired origin. Although certain qualitative differences emerged between the unilateral-lesioned samples and their controls, the authors acknowledged that only one of the 30 lesioned children (a child with a left-sided lesion) had sufficiently pronounced non-fluency to be clinically categorised as a stammerer.

Eisele, a doctoral student of Aram, examined the dissociation in comprehension and production of complex grammar in 25 (mixed age of onset) unilateral-lesioned children (Eisele, 1992). The left-lesioned subjects performed more poorly than their controls on a sentence imitation test, while the right-lesioned subjects performed similarly to their controls. Eisele concluded that the left hemisphere demonstrates early and continuous specialisation for syntactic production.

The findings with respect to scholastic achievement are less clear. Aram and Ekelman (1988) gave the Woodcock-Johnson Psycho-Educational Battery to 20 left- and 12-right lesioned subjects with pre-/peri-natal or acquired injuries, and their matched controls. They found that the left- and right-lesioned subjects achieved lower mean percentile scores on all the measures, but no specific patterns emerged. Indeed, the lesioned subjects appeared to be coping remarkably well educationally despite their neurological disorder.

Vargha-Khadem, O'Gorman and Watters (1985) related receptive and expressive language performance to hemispheric side, age at injury and severity of lesion in 28 left-lesioned, 25 right-lesioned and 15 normal control subjects. Patients with left-sided lesions scored significantly below the controls and the right-sided group on an object naming test (Oldfield and Wingfield, 1964), with the effect being especially pronounced the later the age at acquisition of injury. The left-sided group also scored below the levels of the controls and most of the right-sided patients on the Token Test of Auditory Language Comprehension (De Renzi and Vignolo, 1962). There was an absence of significant deficits in the right-lesioned group in relation to the control group. No correlation was found between extent of cerebral damage and language performance in this sample. It must be noted, however, that in this study patient groups were not differentiated with respect to presence or absence of seizures.

Patients who have undergone hemidecortication have provided a valuable source of information on lateralisation of function, in particular the role of each hemisphere in processing specific aspects of language. The rarity of this procedure necessarily results in comparatively small sample sizes which of course present problems for statistical analysis and interpretation of results. However, studies of these patients offer a unique opportunity to examine the specific cognitive functions of an isolated hemisphere, with the language functions of the right hemisphere attracting special interest.

Dennis and her colleagues have conducted a series of studies comparing and contrasting language performance in small samples of patients who underwent hemidecortication. Dennis and Kohn (1975) compared four left- with five right-hemidecorticated patients, who had suffered early onset hemiplegia with seizures. Age at surgery varied from six to 20 years. They were given a test of comprehension of reversible passive sentences e.g. "The girl is pushed by the boy". The left-hemidecorticates had slower mean reaction times and lower mean scores than did the right-hemidecorticates. Dennis (1980) compared the syntactic performance of six left- and four right-hemidecorticates, some of whom had undergone hemidecortication in infancy while others had surgery far later in chuldhood. Again, the left-hemidecorticates showed subtle difficulties in understanding the rules of complex syntax when compared to the right-hemidecorticates.

Other studies by Dennis and her colleagues have concentrated on three patients, all having Sturge-Weber Syndrome. Two of the patients had the left hemisphere removed and one the right hemisphere during infancy in order to control intractable seizures. Dennis and Whitaker (1976) reported results from the Illinois Test of Psycholinguistic Abilities, ITPA, (Kirk, McCarthy and Kirk, 1968). The right-hemidecorticate showed greater verbal-auditory processing and language proficiency than did the two left-hemidecorticated patients. A study by Lovett, Dennis and Newman (1986) of the same three hemidecorticates extended these findings by studying in depth one aspect of narrative discourse, specifically how pronouns are used to achieve cohesion in retelling stories. One left-hemidecorticate had impoverished pronoun use, while the other produced an abundance of pronouns, some of which were said to be "ambiguous". The discourse of the right-hemidecorticate, on the other hand was rich and appropriate in pronoun use. The authors concluded that an intact left hemisphere is required from the outset to ensure the normal development of complex syntactical and semantic structures in spoken language.

Dennis, Lovett and Wiegel-Crump (1981) addressed the issue of specific hemispheric contribution to the acquisition of written language. They found that their two left-hemidecorticates had problems with some component of speech sound (phonological) analysis in reading. The right-hemidecorticate never violated morphological rules in reading and spelling, while the left-hemidecorticates frequently did so.

The view of proponents of the anti-equipotentiality stance is that the left hemisphere is uniquely specialised to subserve subtle aspects of language function. Damage to the left hemisphere at an early age may permit the right hemisphere to assume gross language functions, but its lack of specialisation prevents it from taking over complex language processes which will remain deficient in these patients even in the long-term.

4.6 Re-evaluation of the Evidence Supporting Anti-Equipotentiality - Methodological Inadequacies of the Early Studies

In the mid- to late-1980's, a reconsideration of the notion of equipotentiality and its antithesis took place. This was prompted by discrepancies and contradictions reported in the literature on brain damage in children. Some studies showed significantly depressed IQs (e.g. Annett, 1973), others did not (Aram, Ekelman, Rose and Whitaker, 1985; Aram and Ekelman, 1986). Some claimed to demonstrate a laterality effect expressed as Verbal-Performance IQ discrepancies (Riva and Cazzaniga, 1986), others did not (Woods, 1980; Aram and Ekelman, 1986). Some studies found that lesions occurring before the age of one year produced more severe overall impairments (Riva and Cazzaniga, 1986), while others demonstrated that lesions after that age produced greater disruption to learning (Woods studies). Before considering in more detail the factors that may alter cognitive outcome in studies of unilateral cerebral injury, the methodological inadequacies of the research promoting anti-equipotentiality will be considered. Several of these inadequacies were highlighted in two critical review papers by Bishop (1983, 1986).

The studies by Aram et al. have met with substantial criticism. The earliest work (Rankin, Aram and Horowitz, 1981) suffered from having too few subjects (only six), and from failing to refer to normative population standards (Bishop, 1983). In Aram, Ekelman and Whitaker's (1986) study of the spoken syntax of hemiplegic children, it was claimed that the left-hemisphere-injured children performed less well when compared to their matched controls than did the rights. Bishop (1988) called into question the accuracy of statistical comparisons made by Aram et al.; when certain statistics were recalculated by Bishop, they failed to achieve the significant levels quoted by the authors. In fact, the end result was that on only two out of 23 measures could a difference be demonstrated between the left- and right-injured children. And as Bishop points out, binomial theorem tells us that, if 23 independent statistical tests are carried out, the probability of two of them achieving significance at the .05 level is as high as 0.321! In the study of language development in hemiplegic children conducted by Aram, Ekelman, Rose and Whitaker (1985), the authors found that the left-hemisphere-damaged group could be differentiated from their controls on a wide range of grammatical and syntactical measures, whereas the right-hemisphere group performed similarly to their controls. However, when the left- and right-damaged groups were compared directly, these differences disappeared. As Bishop (1988) states, Aram et al. failed to find an adequate explanation for this disparate finding, and went on to confidently conclude that their evidence was in favour of the anti-equipotentiality argument.

One further criticism, not specifically raised by Bishop, may be directed at the work of Aram and her colleagues. In their hemiplegic population, the left-lesioned group is well matched by IQ with its selected control group i.e. there are no substantial differences on Verbal, Performance or Full Scale IQ between the left-hemisphere-damaged children and their controls. However, the right-lesioned children have substantially lower Performance and Full Scale IQs when compared with their matched controls. For instance, in the Aram, Ekelman and Whitaker (1987) study, the right-lesioned subjects were scoring 14 points lower on Performance IQ and 12 points lower on Full Scale IQ than were their controls. This discrepancy is evident in other studies also e.g. the Full Scale IQs of the right-lesioned group was 13 points and 11 points below those of their control groups in the studies by Aram and Ekelman 1986 and 1987, respectively. Interestingly, Aram and her associates have not made any attempt to control for this IQ difference in the right-lesioned group, either by including IQ as a matching criterion or through appropriate statistical adjustments (e.g. analysis of covariance). It is possible that the attentional and impulsivity problems observed in the right-lesioned subjects in Aram and Ekelman's 1988 study were related to their lower IQ, rather than reflecting a specific deficit as such.

Bishop (1983, 1988) also re-evaluated the work of Dennis and her colleagues. To begin with, the study by Dennis and Kohn (1975) was criticised on the grounds that the authors had carried out analyses of variance on samples which were too small (four right- and five-left hemidecorticates) and in which the data were skewed, consequently violating the necessary assumptions for use of this statistic. Bishop (1983) then went on to demonstrate in a small normative study that chance performance on a test of reversible passive sentences (which the hemidecorticates showed) is a commonplace finding in normals also, especially those of low-average ability. Dennis and Whitaker (1976) claimed to find differences in auditory/language processing proficiency between one right- and two left-hemidecorticates. But Bishop (1983) pointed out that the profiles of the two left-hemidecorticates were not significantly atypical. Dennis and Whitaker alleged differences in Token Test performance, with the two left cases scoring significantly below the right-hemidecorticate. However, when Bishop converted the raw scores into z scores, all three subjects scored within the normal range and were not significantly different from each other. Bishop (1983, 1988) went on to criticise all of the Dennis studies for, first, making strong and sweeping generalisations from only a very small number of cases, second, for failing to compare the clinical subjects with appropriately matched controls, and finally for interpreting the results on standardised tests in an idiosyncratic fashion e.g. describing scores ranging from the 20th to the 36th centile as being below age-expectation (Dennis et al., 1981).

A further criticism that may be directed at many of the studies of hemiplegic and hemidecorticated patients is the adoption of groups of subjects that cover a very wide range age. To some extent, this is inevitable in view of the rarity of the neurological conditions under study, and the desire for as large and as diagnostically homogeneous groups as possible. However, it can create problems for statistical analysis. Bishop (1988) cautions against the use of raw scores that may produce distorted or artifactual results when the subjects age range is wide. It is preferable in these instances to use z scores (if standardised or normative data are available), or to use statistical adjustments such as analysis of covariance. Another difficulty is that a given test may be measuring very different processes at different ages; this is particularly true of language and educational tests to which children may bring different strategies according to the developmental stage they are at.

Bishop's critical reappraisal of the early studies of unilateral brain damaged children seriously dented the claim of Aram and others that anti-equipotentiality was unequivocally supported by their findings. Indeed much of the evidence, when re-evaluated (and when certain statistics were recalculated) would appear to favour the opposing view i.e. that the two hemispheres are functionally equipotential at birth but become increasingly specialised during the course of development.

4.7 Re-evaluation of the Evidence Supporting Anti-Equipotentiality - Factors Affecting Outcome

The capacity of the injured brain to recover function is understandably modified by a range of factors such as age at onset of injury and size and location of the lesion (what Teuber, 1975, refers to as the "when" and "where" facets of recovery), and the presence of seizures. An explanation for the frequently contradictory results in the anti-equipotentiality research was offered by Aram and Ekelman (1986). They proposed that there has been a tendency for researchers to study heterogeneous groups of brain-damaged children, so including cases with bilateral pathology and seizures alongside those with pure unilateral damage and no seizure disorder. The studies by Woods and his colleagues, Riva and Cazzaniga (1986) and Vargha-Khadem, O'Gorman and Watters (1985) may be criticised on these grounds. In the more recent studies, including those of Aram, greater care has been taken to exclude cases where there is bilateral and/or seizure involvement; this has been made all the more possible by advances in, and the wider availability of, neuroradiological scanning techniques, including CT and Magnetic Resonance Imaging (MRI) scans. However, Aram's work may itself be criticised for failing to take due account of age at onset of injury, with the result that her group is a mix of pre-/peri-natal and acquired cases. The same may be said of Dennis's hemidecorticated sample. In general, studies carried out during the last five to ten years have recognised the powerful influence of these factors, and have either controlled for them or in several instances attempted to assess and quantify their contribution.

The effects of lesion size and of seizures on IQ have been studied by Levine, Huttenlocher, Banich and Duda (1987). They assessed 41 hemiplegic children, most of whom had unilateral lesions of pre- or peri-natal origin. Half the sample suffered from seizures. EEG records were taken along with CT scans. Larger lesion size tended to be associated with lower IQs. Indeed, lesion size accounted for 21 percent of the between subjects variance in IQ. However, there was no effect of EEG abnormality or of seizures on IQ when lesion size was entered as a covariate. Levine et al. concluded that "seizures are rarely a factor in the depressed IQ of hemiplegic children" (p. 33). A later study by Banich, Levine, Kim and Huttenlocher (1990) supported the finding of an association between lesion size and IQ (at least for hemiplegia acquired after the age of one month).

However, studies conducted by Sussova, Seidl and Faber (1990) and by Vargha-Khadem, Isaacs, Van der Werff, Robb and Wilson (1992) have produced contradictory findings to those of Levine et al. (1987) and Banich et al. (1990). Sussova et al. collected IQ, handedness, CT scan and EEG data from 51 hemiplegic children, of whom 19 suffered from clinical paroxysms. They found that the children with paroxysms had significantly lower IQs than those who did not. If the children did not have paroxysms, even if their EEGs showed some focal or epileptic changes, their IQs were comparatively unaffected. Similarly, the study by Vargha-Khadem et al. (1992) demonstrated that the incidence and degree of cognitive deficit was highly related to the presence of seizures and/or severe EEG abnormality. Unilateral brain damage, even if it was extensive (as verified on CT or MRI scans), resulted in few and mild deficits, provided the damage was not accompanied by seizure activity or severe EEG abnormality. Whereas lesions uncomplicated by seizures affected only non-verbal functions, lesions accompanied by seizures adversely affected performance on nearly all the measures, verbal and non-verbal.

A complicating factor in any study that includes patients with seizures must be the influence of medication on cognitive functioning. Rodin, Schmaltz and Twitty (1986) evaluated the effects of medication on WISC performance in 64 epileptic patients. The subjects were initially evaluated at between ages five to 16 years, and re-evaluated after a period of at least five years. All but one patient was taking at least one anti-convulsant drug. The WISC IQ scores showed a significant decrease over time. Phenobarbitol levels were found to be inversely correlated with IQ. These authors concluded that the upper limit of the therapeutic range of phenobarbitol may be toxic with respect to learning abilities. Ideally, studies of cognitive performance that include subjects with seizure conditions should monitor and, if necessary, control for drug levels.

There is very little reliable information concerning the relationship between lesion location and cognitive functioning. In CT studies conducted by Cohen and Duffner (1981) and Kotlarek, Rodewig, Brull and Zeumer (1981), cortical lesions and lesions extending from the surface of the cortex to the lateral ventricle were found to be associated with lower intellectual level than were lesions confined to subcortical white matter and basal ganglia. Aram and Ekelman (1986) attempted to relate characteristics of their hemiplegic samples's WISC-R profiles to the site of lesion. The children were grouped by CT scan findings as presenting prerolandic or retrorolandic involvement, and also as having either cortical or subcortical involvement. Unfortunately, the numbers of children in the resultant groups were so small that statistical analysis was precluded. There was, however, a trend for left-lesioned children with retrorolandic involvement to have relatively lower IQs, and for children with subcortical lesions only to have lower Verbal than Performance IQs. In Levine et al's. (1987) study, no relationship was found between lesion location and IQ. When the lesions were classified according to Cohen and Duffner's criteria, any differential effects on IQ disappeared after lesion size was entered as a covariate.

Filipek, Kennedy and Caviness (1992) discuss the methodological difficulties encountered by studies that attempt to link localisation of function with anatomical structures. First, studies of very large numbers of children are required before the effects of lesion size and specific location on cognitive functioning can be disentangled; given the low incidence of focal lesions in children, this is a difficult criterion to meet. Second, most studies to date have employed CT scanning procedures that are known to give relatively poor grey-white matter resolution; they are consequently restricted to gross anatomical localisation, comparing extent of lesion, left versus right, anterior versus posterior. The outcome of CT studies are affected by procedural variations that are not always standardised within, let alone across, studies e.g. thickness, orientation and position of slice. Finally, it may not be appropriate to employ adult norms for paediatric imaging data. Filipek et al. propose that MRI scans offer more scope for precise levels of anatomical localisation and should, therefore, be the imaging technique of choice in brain-behaviour studies.

The effects of cerebral lesion on language function appears to be related to the age at which the lesion is acquired. In the Levine et al. (1987) study, children with acquired lesions (after one month of age) performed significantly worse than those with congenital lesions on several WISC-R verbal subtests, as well as on the Peabody Picture Vocabulary Test (Dunn and Dunn, 1981). Aram had by 1988 become aware of her failure to take sufficient account of age at onset of injury in the earlier studies of her mixed pre-/peri-natal and acquired sample. Aram (1988) re-appraised the data from her extensive hemiplegic series and reported, first, that left-lesioned injury, with onset prior to one year of age, was associated with homogeneous Verbal, Performance and Full Scale IQs. Second, when the onset of the hemiplegia was after one year, the Verbal IQ was significantly depressed relative to the Performance IQ. Finally, the complementary pattern i.e. Performance IQ lower than Verbal IQ was demonstrated as a non-significant trend in right-lesioned cases with onset after one year. However, age at onset bore no relation to outcome on specific language measures, including tests of educational attainment (Aram and Ekelman, 1988). Earlier studies, including those of Annett (1973), Woods and Carey (1979) and Vargha-Khadem, O'Gorman and Watters (1985) have reported a higher incidence of language difficulties among children with late lesion onset.

4.8 Evidence from Studies of Childhood Hemiplegia and of Hemidecortication Re-appraising Issues of Equipotentiality

Recent studies of hemiplegic children have adopted a less dogmatic stance with respect to the equipotentiality issue. They have taken care to generate larger sample sizes, to adopt more appropriate controls and normative comparisons, and to screen out (or to analyse separately) cases of seizure complication.

Levine et al. (1987) studied the WISC-R IQ scores of 41 hemiplegic children, 50 percent of whom suffered from an ongoing seizure disorder. The sample size was sufficiently large for these children to be considered separately. For the peri-natal group without seizures, the mean IQs fell within the average range but were mildly depressed when compared to control samples. The side of lesion did not have an effect on IQ or subtest scores.

Similar results were recorded in Vargha-Khadem et als.' (1992) study of 82 children having pre- or peri-natal unilateral lesions, and 41 normal controls. Thirty children from the unilateral lesion group suffered from seizures. There were no hemispheric side of injury effects, so the authors collapsed across groups, comparing the combined right and left injured non-seizure cases with the normal controls. The mean Full Scale IQ of the lesioned group was within normal limits, although below the IQ of the normal control group. There was no difference for Verbal IQ, but the Performance IQ of the lesioned group was significantly below that of the control group. Vargha-Khadem et al. interpreted these findings by making reference to two theories of neuropsychological functioning. First, the failure to find right versus left laterality effects supported the equipotentiality hypothesis i.e. that either hemisphere has the ability to subserve speech and language functions in the face of early unilateral damage. Second, the observation of depressed Performance IQ in the clinical sample, irrespective of side of injury, was explained in terms of the "cognitive crowding" hypothesis proposed by Teuber (1975). In this view, the plasticity of the immature brain enables the right hemisphere to mediate language functions, at least grossly, after early injury to the left hemisphere, but at a cost to visuospatial functioning.

Direct evidence for a hemispheric shift in language control in cases of early left-sided injury comes from dichotic listening studies with hemiplegic patients. Carlsson, Hugdahl, Uvebrant, Wiklund and VonWendt (1992) hypothesised that children incurring early left-sided injury should show a shift in both handedness (becoming pathological left-handers) and in ear advantage, reflecting hemispheric transfer of language functioning. They found that 78 percent of their CT-confirmed left injured patients demonstrated a left-ear advantage on a dichotic listening test, in contrast to only 35 percent of normal left-handers. The right hemisphere achieves this hemispheric shift in language control at the expense of its own domain of specialisation i.e. visuospatial functions. It can, therefore, be predicted that unilateral damage to either the left or the right hemisphere will have a depressing effect on Performance IQ, because of the direct suppressing effect on visuospatial functioning in right-lesioned cases and the cognitive crowding effect in left-lesioned cases.

However, the cognitive crowding hypothesis is not the only possible explanation for the lower Performance IQs of hemiplegic children. Successful scoring on Performance tests such as the WISC-R is heavily reliant on intact motor functioning, enabling the child to manipulate the materials easily and to gain bonus points on timed tests through rapid responding. However, hemiplegic children, whether left- or right-lesioned, have substantial motor difficulties because they are frequently able to make use of only one hand when manipulating Performance materials such as blocks or picture puzzles. Brown, Schumacher, Rohlmann, Ettinger, Schmidt, and Skreczek (1989) demonstrated that the "good" hand of hemiplegics was not comparable to either the preferred or non-preferred hand of normal children in a pointing task. The reaching performance of the good hand of the hemiplegic children was poorer than that of normal children, even in those subjects for whom the possibility of bilateral involvement had been excluded (through CT scan verification).

Further support for the equipotentiality and cognitive crowding hypotheses comes from Ogden (1988, 1989). She studied the language, memory and visuospatial functions of two patients who had undergone left hemidecortication surgery in their late teens, after having suffered severe, intractable epilepsy arising from congenital left hemisphere damage. Both patients were seizure-free thereafter, and were followed up by the author after recovery periods of 28 years for one patient, and 16 years for the other. They had stable IQs within the low-average range (80 - 90). Language comprehension and spoken language were remarkably intact, verbal memory scores were considered to be IQ-consistent, and both subjects scored within the normal range on the Token Test.

However, they both performed very poorly on the Rey Complex Figure. On other tests of higher order visuospatial functioning e.g. non-verbal memory, judgment of line orientation, face recognition, and mental rotation, they were described as "moderately to severely impaired". Ogden concluded that these data offer support for the two hemispheres being equipotential with respect to language i.e. that the isolated right hemisphere can mediate language and verbal memory functions to a remarkable degree if the left hemisphere damage occurs in infancy and there is a long recovery period. However, the right hemisphere forfeits its ability to mediate visuospatial tasks when it takes over verbal functions.

Vargha-Khadem, Isaacs, Papaleloudi, Polkey and Wilson (1991) studied three left- and three right-hemidecorticated subjects, and drew rather different conclusions from those of Ogden. These patients were studied in pairs formed on the basis of age at the commencement of epilepsy i.e. congenital versus acquired cases. The four patients with later onset epilepsy had Rasmussen's encephalitis, while the two patients with early onset of epilepsy had acquired infantile hemispheric disease (one with onset at 15 months, the other at two years). The authors evaluated their performance on a range of language measures against that of 12 normal controls, eight patients having had left temporal lobectomy and 10 (seizure-free) patients with a congenitally sustained left hemisphere cerebral insult. Vargha-Khadem et al. found that their hemidecorticated patients had low IQs, averaging in the mid-60s, but their memory quotients (measured on the Wechsler Memory Scale, Wechsler and Stone, 1945) were commensurate with their Wechsler IQs. However, the left-hemidecorticates were significantly poorer than the rights and the controls on a range of standardised and experimental language tests (in contrast to the right-hemidecorticates who scored at a level similar to the control groups). The left-hemidecorticates were disadvantaged on the Oldfield and Wingfield Object Naming Test and the Test for Reception of Grammar, TROG (Bishop, 1982). They showed greater variability in responding on the Token Test. On an experimental test of knowledge of morphological markers, that employed both real and nonwords, the left-hemidecorticates were able to process and produce markers for the items containing real words but had greater difficulty with the nonword items. Vargha-Khadem et al. concluded that the isolated right hemisphere is capable of subserving aspects of everyday verbal communication, as exemplified by IQ and general memory and language tests. However, it is deficient in accurately processing complex grammatical, syntactical and probably phonological information, particularly in the absence of familiar cues.

The results of Vargha-Khadem et al. study appear to contradict those of Ogden who suggested that the isolated right hemisphere can mediate verbal language functions to a remarkable degree. The differences may, however, be accounted for by the factors of age at onset of injury (and seizures), and of length of recovery period following surgery. In Ogden's study both hemidecorticates had congenital hemiplegia and early seizure onset. In the Vargha-Khadem et al. study, it was evident that, in all six patients, some degree of language function had developed before the onset of the disease. In addition, there was some suggestion from the pattern of scores that the earlier the left hemisphere injury the less pronounced the language deficit. Thus, the capacity of the right hemisphere to take over even subtle language abilities may be increased if the injury is incurred sufficiently early to capitalise on the functional plasticity of the developing brain. However, if the injury is incurred at a later age, after speech and language has been established, the potential for reorganisation within the remaining (less plastic) neural space is markedly reduced. In addition, the process of recovery of function after surgery may be slow and long-term. Ogden's cases had very long recovery periods after surgery before they were subjected to psychometric testing, while for Vargha-Khadem et al.'s subjects the time elapsed between surgery and testing was far shorter.

Zaidel (1980) compared the spoken and written language skills of two children, RS and DW, both of whom had sustained the lesion that resulted in hemidecortication well after the appearance of normal comprehension and speech, at ages 10 and seven years respectively. RS had a left hemispherectomy, and DW a right hemispherectomy. RS's speech was dysfluent, frequently agrammatic, stereotyped and telegraphic, though semantically correct. RS could not read, write or perform simple arithmetic. DW had fluent speech, and although his reading and writing were below age-expectation, he was nonetheless capable of demonstrating phonetic rules. The findings provide support for the relative functional independence of hemispheric subsystems. The left hemisphere was demonstrated to be dominant in the production of speech and in the processing of phonetic and syntactic information. Zaidel concluded that the available evidence does not support a major role for the right hemisphere in reading acquisition. However, there is evidence to show that the right hemisphere plays a contributory role in specific aspects of language functioning such as auditory language comprehension, acoustic lexical analysis, semantics and certain Piagetian cognitive operations e.g. conservation.

Patterson, Vargha-Khadem and Polkey (1989) addressed the question of what specific contribution is made to reading by the isolated right and left hemisphere of hemidecorticates. They assessed in detail the reading processes and subskills of two originally right-handed teenaged girls who had undergone complete hemidecortication (one left, one right) for intractable epilepsy resulting from late-onset encephalitis. Both girls had developed normal language and reading capacities prior to the onset of their illness. The reading performance of the right-hemidecorticated patient, while not as advanced as that of a normal adolescent, showed no abnormality in any sub-component of reading skill. The authors concluded that the right hemisphere plays no necessary role in supporting reading skills, the same conclusion as that drawn by Zaidel (1980). It is possible to demonstrate an essentially normal reading pattern in an individual having only the left hemisphere functionally intact. On the other hand, the reading performance of the left-hemidecorticated patient was very poor. In addition to having generally greater difficulty in reading overall, she could not manipulate phonemes within words (by adding or deleting them), she could not produce rhyme and she was unable to read nonwords. This suggests that fine phonemic processing is an ability completely lateralised to the left hemisphere. Moreover, her speech comprehension and production, though not good, were nonetheless superior to her reading. Patterson and et al. suggest that, in response to a deteriorating dominant hemisphere, the brain will re-establish as much basic communication skill as possible in the other hemisphere, giving priority to spoken over written language.

While the studies of hemidecorticated patients have substantially added to our knowledge of specific hemispheric contribution to cognitive functioning, their results need to interpreted with some caution. Vargha-Khadem and Polkey (1992) point to four factors that should be taken into account when drawing conclusions from the results of these studies. First, cognitive outcome after hemidecortication is always assessed after a longstanding disease process has affected the functional reorganisation not only of one hemisphere but of both. Second, the effect of the disease process on the "intact" hemisphere is likely to be highly complex, involving both interference with that hemisphere's functions by the seizure disorder as well as forced reorganisation of its function due to the functional failure of the diseased hemisphere. Also, uncontrolled experiential variables are certain to affect any reorganisation of cognitive function, if not its recovery. Their final caution relates to the modifying influence of temporal, locus of injury and severity factors. Hence, the need for long-term follow up of surgical cases, preferably on a longitudinal basis, to chart changes in rate of development and later emerging skills.

4.9 Hemiplegia - Change over Time and the Developmental Perspective

In 1990, Banich et al. reported a study of 41 hemiplegic children, in which they examined the effects of time elapsed since lesion onset on cognitive functioning. They found that, for those children having congenital hemiplegias, the longer the time elapsed between lesion onset and test age, the lower the level of intellectual functioning, as measured by both Verbal and Performance IQs. This effect held even after controlling for the size of the lesion. It appeared that the children's scores remained close to age-appropriate norms until about the age of six years, after which there was a slowing down in the rate of cognitive growth and development. The authors explain their findings by suggesting that the reorganisational capacity of the young lesioned brain is adequate to support early developing functions but not the more complex functions which emerge later as the brain matures. As Banich et al. point out "Of course, our findings await confirmation by a longitudinal study" (p. 45). A confounding factor in this study was the failure to take account of, or to control for, the effects of seizures. Whether the slowing down in cognitive growth is a general finding for all hemiplegic children or whether it is specific to those patients with seizures, who experience continuous interference effects, is an important issue for study.

It is only in very recent years that neuropsychological research has taken the lead from the cognitive-developmental literature and begun to study brain-damaged children longitudinally. Certainly, if we are to accurately measure and chart changes in the rate of general development and the time of emergence of specific (especially language) skills in this clinical population, cross-sectional (correlational) studies of children at different ages are not adequate for this purpose. Also, if we are to assess cognitive and educational outcome in terms of predictor variables, it is only longitudinal studies that can unequivocally establish timing of events and allow us to draw conclusions relating to causation.

An intended large scale longitudinal study of hemiplegic children from birth onwards is being conducted in the United States, involving several well known researchers including Dorothy Aram, Elizabeth Bates and Joan Stiles, and a number of university centres and hospitals. One of the first reports was of a study of 27 hemiplegic children, on whom language data were obtained between 12 and 35 months of age, the lesion having being acquired pre-natally or within the first six months of life (Thal, Marchman, Stiles, Aram, Trauner, Nass and Bates, 1991). CT and/or MRI scans confirmed the focal nature of the brain injury and provided data on lesion size and location. Unfortunately, no information was provided about the seizure status of the children. While the study purported to be longitudinal in nature, having in theory three data points for each child, the reality was that only five children supplied data for all three points, with 17 subjects having only one data point available. The measures of language development were derived from parental report instruments developed by Bates and her colleagues i.e. there was no direct testing or observation of the children's receptive or expressive language. Although the study appeared to have no control group as such, there was fairly recent (mid- to late-80s) normative data available for the instruments employed. A notable absence in this study was that of any report of standardised measures of the children's general cognitive (including non-verbal) status. The authors were careful to draw only tentative and speculative conclusions from what they consider to be preliminary data from an ongoing longitudinal study. In general, they found that there was a tendency for their hemiplegic subjects to be delayed in the early stage of language development, with a relatively large number of comprehension and production dissociations (or mismatches) being obtained.

In the 12-16 month phase, both the left- and right-lesioned groups were equally delayed in the comprehension and production of words. In the later phases, up to 35 months, there was weak support for right hemisphere damage resulting in comprehension delay, and left hemisphere damage leading to greater deficits in speech production. There were no significant effects of lesion size on any of the linguistic measures.

Feldman, Holland, Kemp and Janosky (1992) conducted a smaller scale longitudinal study of nine hemiplegic preschool children (five left- and four right-lesioned subjects), for which three observations on language functioning were available for each child. The unilateral focus of injury was confirmed through imaging but, as with the Thal et al. study, no information was provided relating to the children's seizure status. Language samples generated from parent-child interaction were transcribed, the main dependent measures being mean length of utterance, vocabulary size, and the number of different syntactic structures used. No general cognitive or non-verbal measures were taken. There was no control group, but reference was made to normative data in the literature, and a validation procedure with a subgroup of subjects' siblings was carried out. Growth trajectories for the language measures were produced which proved to be remarkably stable; the slopes were comparable to those seen in normal children. No side of injury effects were apparent. However, the **onset** of vocabulary and syntactic skills was noted to be delayed in several of the hemiplegic children. It was concluded that both hemispheres play a critical role in the very earliest stages of language acquisition, and that, for many children with unilateral lesions, language outcome, after an initial delay, is seemingly normal.

Longitudinal research into the cognitive development of brain-damaged children is still in its infancy. Obtaining a sufficiently large sample of children within a restricted age range is a major logistic problem not experienced by those studying normal populations. The longitudinal programme recently commenced in the United States is promising, although to date only 40 subjects have entered the programme, and one study centre has withdrawn (Bates, personal communication, 1993).

4.10 Conclusion

Populations of children with unilateral brain injuries offer researchers the possibility of testing hypotheses regarding hemispheric equipotentiality, the developing brain's capacity for functional reorganisation (and consequent sparing of function), and the cost of such reorganisation in terms of loss of other aspects of cognitive function. However, evidence is accumulating to show that none of these hypothesised processes are all or none, and that they may be modified by factors such as age at injury, locus and extent of injury, age at testing, and presence of seizures. Neuropsychological research needs increasingly to test the limits of these processes, in relation to specific as well as global cognitive skills. It is proposed that what is required is a shift beyond the addressing of general issues such as equipotentiality in favour of exploring the relationship between specific cognitive skills during the course of development. The survival of certain skills above others in the face of injury may point to both their robustness and their meaningfulness. In the present study, phonological skills and their relation to early literacy development constitute the specific cognitive area under focus.

Chapter 5

A Longitudinal Study of Language Development in Hemiplegic Children
Design of the Project and IQ Data

5.1 Introduction

Longitudinal studies have increasingly become the research design of choice to examine developmental processes in normal children. When combined with controlled laboratory experiments, they provide important information about causation and prediction of outcome of cognitive functions such as language and reading skill. In clinical populations, especially the study of brain-damaged children, longitudinal paradigms have rarely been employed, and even then only comparatively recently. While cross-sectional information is available on how brain-damaged children, such as those with hemiplegia, function (see Chapter 4), the important data about course of development and causation are generally absent. The multi-centre study of hemiplegic children in the US is one of the few highly promising studies, but it has recruited only 40 subjects to date, and is still at the stage of ongoing data collection (Bates, personal communication, 1993). Reservations are expressed about the methodology and content of the early reports (e.g. Thal et al., 1991), particularly in terms of "missing" data points and the use of parental report instruments as opposed to direct observation or the use of standardised measures (see Chapter 4.9 for more details). Other recent attempts at longitudinal data collection in brain-damaged children (e.g. Feldman et al., 1992) may be criticised on the grounds of too few subjects (only nine in the Feldman study), absence of information relating to seizure status, and failure to employ matched control groups.

Chapters 5, 6, 7 and 8 describe a longitudinal study of young hemiplegic children that avoided most of the methodological pitfalls characteristic of the recently reported longitudinal studies. The 38 participating children, all of whom had lateralised insults of pre- or peri-natal origin, made up a comparatively large sample, given the clinical nature and the narrow age range from which the subjects were selected. The children underwent extensive cognitive evaluation at three equidistant points in time over a two-year period. Their performance on a range of standardised and experimental tests was compared with that of a control group (n = 20) of children with non-progressive medical disorders, but without neurological conditions (medical controls). None of the hemiplegic children was lost from the study and all 38 children provided data for all three possible data points. One medical control could not be traced in the final year of data collection; consequently, 19 control subjects completed all three data points, while one child supplied data for two out of the three possible data points. Account was taken of the seizure status of the children in the hemiplegic sample; the data from children having seizure conditions were analysed separately from those who were seizure-free.

A number of developmental neuropsychological issues of theoretical and clinical relevance will be addressed in the second half of this thesis.

First, there are the intertwined issues of equipotentiality of the two hemispheres, functional reorganisation and/or compensation, and the costs of such reorganisation on the subsequent development of cognitive functions (i.e. cognitive crowding). Equipotentiality refers to the equal capacity of either hemisphere to subserve language functions in the face of early unilateral damage (Lenneberg, 1967). It is presumed that the plasticity of the immature brain enables compensation to take place through the process of functional reorganisation, such that the remaining intact regions within the brain take over the functions of the damaged portions. However, the sparing of language functions following on after early left hemisphere injury is often achieved at the cost of visuospatial abilities and executive functions (Vargha-Khadem, 1993). This is as a result of competition, or in Teuber's terminology "crowding", within the remaining intact neural space (Teuber, 1975). Recent research has on the whole supported the notion of equipotentiality, as opposed to that of anti-equipotentiality (see Chapter 4 for a full discussion). It is consequently hypothesised that there will be few left-right laterality differences in those aspects of cognitive function that have already received attention from other researchers, notably verbal and non-verbal intelligence and language. However, this study also aimed to explore the existence of laterality differences in previously unexplored domains, namely phonological awareness, literacy and numeracy skills. If it proves to be true that there are no left-right differences for intelligence and language, it follows that it will be unlikely that phonological and literacy/numeracy skills will depend on hemisphere-selective lateralised processes.

To address practical and theoretical issues relating to the developing brain's capacity for reorganisation after early injury, the hemiplegic children's performance on a relatively wide range of cognitive tests will be compared to that of a medical control group. The failure to find significant and/or pervasive differences would marshall further support for the commonly held view that the young brain has a remarkable capacity to functionally reorganise itself and so compensate for the consequences of the damage incurred. Conversely, the presence of substantial differences would argue the case for limitations in reorganisation of function. In the present study, it is possible to address the issue of whether early injury results in the absence of generalised cognitive impairment, while leading to domain specific deficits. An interpretation in terms of the cognitive crowding hypothesis (Teuber, 1975) would then be appropriate i.e. following early brain injury, reorganisation takes place in such a way that language functions are preserved and subserved in the intact regions. Teuber's crowding hypothesis was developed specifically in relation to **inter-hemispheric** transfer of language abilities to the undamaged right hemisphere following early left hemisphere injury. Gross language abilities may be subserved by the right hemisphere but its lack of specialisation, combined with damage to language areas of the left hemisphere, could well result in subtle and specific language deficits. In addition, the visuospatial functions of the right hemisphere are likely to become compromised as a result of competition within the limited neural space available. The prioritising of language functions by the right hemisphere could result in the arrest, "slowing down" or even pathological development of visuospatial skills. The outcome should be a lowered Performance IQ, and some, possibly selective language deficits. Teuber's crowding hypothesis may be extended to consider the possibility of **intra-hemispheric** transfer of language functions in response to early left hemisphere injury. Reorganisation of language skills within the remaining intact regions of the left hemisphere might well result in language decrements, but one would not predict a decline in Performance IQ.

The selection of a young sample of subjects necessarily restricts the range and complexity of skills that may be studied. Within the present sample, gross verbal and non-verbal abilities should be well established, but some of the more subtle and complex aspects of language function, which would be expected to develop at a later age, cannot be evaluated. Consequently, even if these subjects appear to have well preserved language functions at this point, this cannot give assurance that they will be able to develop the more advanced skills associated with later stages in development. It has been suggested that the reorganisational capacity of the young lesioned brain is adequate to support early developing functions, but not more complex functions (for instance, metacognitive skills) that would be expected to develop later, as the normal brain matures (Goldman, 1974; Banich et al. 1990).

A second important issue to be addressed in this study was that of the effects of seizures on the hemiplegic children's cognitive processes and attainments. Sussova et al. (1990) and Vargha-Khadem et al. (1992) found that hemiplegic children also suffering from seizures scored significantly lower on verbal and non-verbal IQ and on memory measures than did their seizure-free hemiplegic counterparts. It was hypothesised that those hemiplegic children with seizures would show substantial cognitive deficits when their performance was contrasted with that of both the medical control group and the seizure-free hemiplegic group. It follows that the hemiplegic children with seizures should also be adversely affected in their ability to develop phonological awareness and educational skills. This would suggest that the presence of seizures markedly interferes with the developing brain's capacity for reorganisation and compensation following a unilateral cerebral insult.

Third, the availability of extensive data would permit specific questions pertaining to hemispheric specialisation, language representation and literacy or numeracy performance in the immature brain to be addressed. Measures of handedness and ear preference provide information about the children's cerebral motor reorganisation and the extent of right hemisphere processing of language, respectively (Chapter 6). Tests of language, phonological awareness, literacy and numeracy enable the study of specific domains of language functions that may be impaired in children with unilateral insults (Chapters 6 and 7). Partialling out IQ means that group difference in these skills can be evaluated independent of the children' gross levels of function. This is of special importance in view of the likely generalised cognitive impairment of the children with seizures. An attempt will be made to relate the hemiplegic children's phonological, reading and spelling skills to the model of early literacy development generated in Chapter 2 (Chapter 8). Of particular interest is the question of whether children with a neurological insult learn to read in the same way as normal children, or whether they make use of alternative cognitive processes and skills in the beginning stages of reading acquisition.

Finally, the longitudinal nature of the study enables comparison between the hemiplegic children's cognitive functioning and that of the medical controls at three different time points. In addition to providing a more reliable picture of the children's performance (in test-retest terms), there will be the opportunity to assess whether the similarities and/or differences between the groups change over time i.e. with increasing age. A recent study by Banich et al. (1990) showed that in congenital hemiplegics the longer the time elapsed since lesion onset the lower the level of intellectual functioning, an observation suggesting that such children show a slowing down in their rate of cognitive growth as they get older. However Banich et al. failed to take account of seizure presence in their sample of hemiplegic children; whether the slowing down was greater for the seizure subjects is an issue worth exploring. The "slowing down" hypothesis and the contribution of seizures requires confirmation using longitudinal data such as this study affords.

Most research on hemiplegic subjects has investigated reorganisation and compensation in older children, often in wide-ranging age groups, and through cross-sectional studies. The present investigation is unique in that it addresses these issues, together with the processes of development over time, through the study of a younger group of children, spanning a very restricted age range, and at three equidistant points in time over a two-year period. The fact that the children were recruited when aged only three to five years meant that there would be the opportunity to follow through their cognitive development into later childhood.

Chapter 5 will outline the methodology and design of the project, and present data pertaining to the intelligence of the subjects within the sample.

5.2 Method

5.2.1 Subjects

Twenty three patients with left hemisphere insult, 15 patients with right hemisphere insult, and 20 control subjects were studied. The hemiplegic patients were recruited mainly through the London Hemiplegia Register (Goodman and Yude, 1993), maintained at the Hospital for Sick Children, Great Ormond Street. Additional subjects were sought via Consultant Neurologists or Paediatricians based at various hospitals in Southern England. The criterion for selection of patients was the existence of an identifiable degree of hemiparesis, resulting from a unilateral brain insult sustained pre- or peri-natally. Each patient's Consultant Paediatrician or Neurologist was requested to complete a Medical Questionnaire (Appendix 5.1), in order to confirm the clinical diagnosis, to delineate the medical history, and to provide relevant neuroradiological information. Of the total sample of 38 hemiplegic children, 24 had undergone some form of neuroradiological or electrophysiological investigation (computed tomography, ultrasound or electroencephalography). Patients with bilateral involvement, other confounding disorders, or those who had incurred the brain insult after the pre- or peri-natal period were excluded.

The hemiplegic patient groups with left- or right-hemisphere insult were further subdivided on the basis of presence or absence of clinical seizures. The children allocated to the seizure groups were those who had suffered non-febrile seizures after the neonatal period; some of the children had ongoing seizure conditions, while others had experienced seizure episodes when younger but were not currently experiencing convulsions. Some of the children with seizures were receiving anti-convulsant medication during the course of the study, while others were not. The non-seizure group consisted of children who had not had seizures at any stage in their development, or who had had only seizures during the neo-natal period and had had none since. Patients with IQ scores below 70 were excluded from the sample.

The resulting groups were designated as follows: LNS (n = 15) for left hemisphere insult with no seizure disorder; LS (n = 8) for left hemisphere insult with seizure disorder; RNS (n = 11) for right hemisphere insult with no seizure disorder; and RS (n = 4) for right hemisphere insult with seizure disorder. The children's diagnoses and the bases on which these were made (derived from information in the Medical Questionnaire) are described in Appendix 5.2. The hemiplegic children ranged in age from 3 years 6 months to 6 years 8 months, with a mean age of 4 years 11 months (s.d. = 9.0 months), at the outset of the study.

The control group consisted of 20 children, all attending outpatient Growth Clinics at the Hospital for Sick Children, Great Ormond Street. They suffered from chronic medical conditions that affected their physical growth. Their Consultant Paediatricians at the Hospital confirmed that none of the children had known insults to the telencephalic regions of the brain i.e. the neocortex, basal ganglia and limbic structures (Kolb and Wishaw, 1990). Eight children had Growth Hormone Deficiency, six were of short stature of either genetic or unknown origin, five had defined genetic syndromes, and one had hypothyroidism. None of these conditions (apart from one of the syndromes) is known to have associated cognitive deficits (Winter and Baraitser, 1991). Of the children with genetic syndromes, one had Turner's Syndrome, two had Russell-Silver Syndrome, one had McCune-Albright Syndrome and the remaining child had Aarskog Syndrome. All four syndromes are characterised by small stature together with other minor physical features (e.g. cafe au lait skin pigmentation), but the only one known to have significant associated cognitive effects in some children is Turner's Syndrome (Temple and Carney, 1993). The control children, designated MC (medical controls), ranged in age from 3 years 10 months to 5 years 6 months, with a mean age of 4 years 7 months (s.d. = 6.6 months) when the study began.

Footnote: It is acknowledged that some of the subjects in the medical control group might have cognitive deficits arising from the underlying medical condition. This points to the difficulty of selecting an appropriate medical control group.

5.2.2 Procedure

Data were collected during a series of individual sessions, each lasting approximately 20 - 30 minutes, conducted over one to two days in each year. Between four and five sessions were conducted on a given day, punctuated with generous play and "snack" breaks.

5.2.3 Tests and Materials - Rationale

The tests and materials selected for the study assessed the following domains of function: intelligence, hand and ear lateralisation, language, phonological awareness, literacy and numeracy attainments. These were chosen because they covered a wide range of skills important to children's day-to-day learning, communication, and in particular, educational progress.

Intelligence (IQ) tests are important as measures of global functioning, and are essential for providing baseline levels against which selective cognitive deficits may be evaluated.

The handedness inventory and dichotic listening tests were given in order to determine whether the early unilateral lesions suffered by the hemiplegic children had altered the normal pattern of functional specialisation of the cerebral hemispheres; these results might then provide a theoretical framework within which to interpret other findings from the study.

The language tests chosen tapped a range of receptive and expressive verbal skills. Apart from IQ, language skills have been most widely studied in hemiplegic children in order to address the frequently controversial issues of equipotentiality of the two hemispheres for the support of language functions, and the developing brain's capacity for functional reorganisation in the face of early injury.

The major focus of this thesis is the study of young children's early literacy development and its special relationship to phonological awareness. A model of "normal" beginning reading was developed in Chapter 2. The same phonological awareness and attainment tests were administered to the clinical samples in order to determine whether the phonological skills that contribute to literacy development in normal children apply also to children with early acquired hemispheric injury, or whether a departure from this model is necessary to explain the acquisition of reading and spelling in such children.

The IQ tests, the results from which are discussed in this chapter, are described below. Data derived from the handedness inventory, the dichotic listening and the language tests are described in full in Chapter 6. The phonological awareness, literacy and numeracy data are discussed in Chapters 7 and 8. The full list of tests, and the measures used in the statistical analyses, are presented in Appendix 5.3.

5.2.4 The IQ Tests:

In Year 1 of the study, the following subtests from the Wechsler Preschool and Primary Scale of Intelligence, WPPSI, (Wechsler, 1963) were administered: Similarities, Arithmetic, Vocabulary and Comprehension from the Verbal Scale; and Picture Completion, Block Design, Mazes and Geometric Design from the Performance Scale. In Year 3, a shortened version of the Wechsler Intelligence Scale for Children-Revised, WISC-R, (Wechsler, 1976) was administered, comprising two Verbal subtests (Similarities and Vocabulary), and two Performance subtests (Picture Completion and Block Design).

5.3 Results

5.3.1 Preliminary Data Analyses

The data were examined for skew, kurtosis and significant outliers. Most of the measures conformed to acceptable normal distributions. This was particularly true of the larger non-seizure groups, though there was a tendency for the smaller seizure groups to show significant positive kurtosis across a large number of measures. Analysis of Variance, the statistical test predominantly used to analyse the data, is known to be fairly robust to departures from normality (Ferguson, 1981). However, when a measure was found to show significant skew and kurtosis in all, or most of the subject groups, the data were subjected to the appropriate logarithmic transformation (Tabachnick and Fidell, 1989). The transformed data were then used in the subsequent analyses. Post hoc analyses were conducted using either the Newman-Keuls procedure (Winer, 1971), t-tests (Ferguson, 1981) or through planned contrasts (O'Brien and Kaiser, 1985).

Preliminary analyses confirmed that the children in all five participating groups were well matched on age i.e. the groups did not differ significantly with respect to age ($F[4,57] = 0.89$, ns). The means and standard deviations of the Year 1 age scores for the groups are presented in Table 5.1.

Table 5.1 - Means and standard deviations of the subjects' ages in Year 1 for the medical control (MC) and the left- and right-hemispheric-insult groups, without and with seizures (LNS, RNS, LS and RS, respectively)

Group	**Age (in months)**
Medical Controls (MC)	55.50 (6.64)
Left Side, No Seizure (LNS)	60.67 (10.00)
Right Side, No Seizure (RNS)	59.18 (9.84)
Left Side, With Seizure (LS)	57.00 (7.52)
Right Side, With Seizure (RS)	59.00 (7.79)

Standard deviations are given in parentheses.

5.3.2 <u>Preliminary Analyses of the IQ Data</u>

Examination of the IQ data confirmed that the measures of Verbal, Performance and Full Scale IQ that were to be used in the analyses were all acceptably normally distributed.

Because of concern that the children in Group MC with defined genetic syndromes (in particular, the child with Turner's Syndrome) might be substantially different from the other control children in their cognitive presentation, the IQ data for this group were carefully examined. First, the "box plots" for each of the IQ measures were studied for extremes or outliers; none were evident for any of the measures. Second, the IQ scores for each of the syndrome subjects were compared with the group means obtained from the remaining 15 subjects. None of the syndrome children had IQ scores that were more than one standard deviation below the means of the group of 15. The child with Turner's Syndrome did show a pattern consistent with that documented in a proportion of Turner's girls i.e. Performance IQ lower than Verbal IQ, but only to a very mild degree. Indeed, this child had a Verbal IQ of 110 and a Performance IQ of 99 in Year 1, and a Verbal IQ of 108 and a Performance IQ of 100 in Year 3. Since the IQs of the five children with syndromes were not considered to be unrepresentative of the group as a whole, their scores were retained in these analyses.

5.3.3 Rationale of Analyses

Five series of statistical analyses on the IQ data were conducted. **Series 1 Analyses** investigated the effects of hemispheric side of insult and of seizures on IQ in the total hemiplegic sample (excluding Group MC). Since the effect of hemispheric side of insult was found to be non-significant, the IQ scores were, therefore, collapsed over this variable, and a further series of analyses, **Series 2 Analyses**, on the IQ data were carried out, this time incorporating Group MC. **Series 3 Analyses** examined group differences in relation to Verbal versus Performance IQs. The Series 2 and 3 Analyses compared the hemiplegic groups' IQ scores with those of Group MC. It was important to consider, first, whether Group MC was representative of the normal population of children, and second, to compare the mean IQs of the Groups with those of an hypothesised normal population (in which the mean is 100 and the standard deviation 15). Consequently, in the **Series 4 Analyses**, the children's IQ scores were adjusted for time elapsed since standardisation of the IQ tests, and were then compared with the hypothesised population mean. Finally, in the **Series 5 Analyses**, the change in the groups' IQ scores over time i.e. changes related to increasing age were studied.

In some analyses, the Year 1 WPPSI IQ scores were based on all eight subtests administered (Series 1 and 2 Analyses). However, in other analyses, particularly when a comparison was being made of the subjects' IQs over the course of Years 1 to 3, "short" WPPSI IQs were used (Series 3, 4 and 5 Analyses). These were based on the subtests common to the two years in which IQ data were collected i.e. Similarities and Vocabulary making for a "short" WPPSI Verbal IQ, and Block Design and Picture Completion making for a "short" WPPSI Performance IQ. The "short" WPPSI Full Scale IQ, that was used in some analyses, was the mean of the short Verbal and Performance IQs.

5.3.4 <u>The IQ Analyses</u>

5.3.4.1 <u>Series 1 Analyses: The effects of hemispheric side of insult and of seizures on IQ</u>

In the first series of analyses, the independent variables were those of hemispheric side of insult (left versus right), and of seizure disorder (presence or absence), while the dependent measures were Verbal, Performance and Full Scale IQ scores from Years 1 and 3 of the study. Separate analyses were carried out on each of the dependent measures for each of the years, 1 and 3.

In Year 1, there were significant main effects of seizures on all the IQ scores (Full Scale IQ - $F[1,34] = 7.47$, $p < .05$; Verbal IQ - $F[1,34] = 4.54$, $p < .05$; Performance IQ - $F[1,34] = 8.93$, $p < .01$). There were no effects of hemispheric side of insult (Full Scale IQ - $F[1,34] = 0.40$, ns; Verbal IQ - $F[1,34] = 0.56$, ns; Performance IQ - $F[1,34] = 0.14$, ns). Moreover, the hemispheric side of insult did not interact with the effects of seizures (Full Scale IQ - F[1,34] = 0.54, ns; Verbal IQ - F[1,34] = 0.50, ns; Performance IQ - F[1,34] = 0.60, ns).

In Year 3, there were significant effects of seizures on short WISC-R IQ Full Scale IQ and Performance IQ (F[1,34] = 8.31, p < .01; F[1,34] = 10.40 p < .01, respectively). The seizures effect on Verbal IQ was almost significant (F[1,34] = 4.06, p = .052). There were no effects of hemispheric side of insult on the IQ measures (Full Scale IQ - F[1,34] = 0.03, ns; Verbal IQ - F[1,34] = 0.03, ns; Performance IQ - F[1,34] = 0.61, ns). Nor did the hemispheric side of insult interact with the effects of seizures (Full Scale IQ - F[1,34] = 0.14, ns; Verbal IQ - F[1,34] = 0.06; Performance IQ - F[1,34] = 0.36, ns).

5.3.4.2 Series 2 Analyses: The effects of unilateral injury and of seizures on IQ

Since Analysis 1 had established that there was no effect of hemispheric side of insult on IQ scores, it was judged legitimate to collapse across this variable in the subsequent analyses.

Analyses of variance were conducted, comparing the IQ scores of the following three groups of children - HNS (hemispheric injury without seizures), HS (hemispheric injury with seizures) and MC (medical controls) - in Years 1 and 3 (see Table 5.2).

In Year 1, there was a significant difference between the Full Scale IQ scores of the Groups (F[2,55] = 9.55, p < .001). Newman-Keuls post hoc tests revealed that children in Group HS had lower Full Scale IQs than those in both Groups HNS and MC, but that the children in Group HNS were not significantly below those in Group MC. An identical pattern emerged for both the Verbal IQ (F[2,55] = 6.16, p < .01) and the Performance IQ (F[2,55] = 10.25, p < .001), with post hoc tests revealing significantly lower Verbal and Performance IQs for the children in Group HS when compared to those in Groups HNS and MC.

Table 5.2 - Means and standard deviations of the IQ Scores obtained in Years 1 and 3 for the hemiplegic groups without and with seizures (Groups HNS and HS, respectively) and the medical control group (MC)

	MC	HNS	HS
Year 1 (Full WPPSI)			
Verbal IQ	114.2 (11.7)	107.9 (15.5)	95.9 (14.5)
Performance IQ	107.0 (11.1)	100.5 (14.1)	84.6 (16.2)
Full Scale IQ	111.5 (11.1)	104.5 (14.2)	89.9 (15.7)
Year 1 (Short WPPSI)			
Verbal IQ	114.2 (10.2)	108.3 (13.7)	99.8 (13.8)
Performance IQ	103.5 (7.0)	101.4 (11.2)	89.4 (11.7)
Full Scale IQ	108.8 (7.5)	104.9 (10.9)	94.6 (12.1)
Year 3 (Short WISC-R)			
Verbal IQ	112.1 (15.2)	107.5 (16.6)	95.5 (17.0)
Performance IQ	107.6 (8.2)	99.8 (10.1)	87.8 (10.4)
Full Scale IQ	109.6 (10.2)	103.6 (11.4)	91.5 (12.1)

Standard deviations are given in parentheses.

Again, in Year 3, the Groups differed in Full Scale IQ ($F[2,54] = 9.74$, $p < .001$). As in Year 1, Newman-Keuls tests demonstrated that Group HS scored significantly below both Groups HNS and MC. There were also Group differences in Verbal IQ ($F[2,54] = 3.92$, $p < .05$). Group HS scored significantly below both Groups HNS and MC, but there was no difference between Group HNS and MC. The Groups differed significantly in Performance IQ, ($F[2,54] = 15.60$, $p < .001$). Post hoc tests confirmed that Group HS scored significantly below both Groups HNS and MC, **and** Group HNS scored significantly below Group MC.

The children in Group HNS scored significantly below Group MC only in Performance IQ in Year 3. In order to determine whether the specific Performance IQ decrement of Group HNS could be attributed to poorer visuospatial functioning or to reduced motor capacity, the children's WISC-R Block Design subtest scores were analysed further. This subtest was selected because it requires both visuospatial processing and fine motor coordination; the child achieves a score that takes account of both accuracy of the completed block patterns and also speed of completion since time-related bonus points may be earned. To differentiate between the two possible explanations for the lower Performance IQ of Group HNS relative to Group MC, t-tests were conducted, comparing the performance of these two groups on the Block Design subtest scored in two different ways. First, the groups were compared using the Block Design raw scores obtained in accord with standard WISC-R administration procedures. These scores took account of both accuracy and speed of responding as time bonus points were recorded. Group HNS scored significantly below Group MC ($t[43] = 2.17$, $p < .05$); the mean score for Group HNS was 10.9 (s.d. 6.2), and for Group MC 14.9 (s.d. 6.2). In the second analysis, raw scores based on accuracy only were used i.e. the number of correctly completed patterns, <u>without</u> time bonus points. Once again, Group HNS scored significantly below Group MC ($t[43] = 2.09$, $p < .05$); the mean score for Group HNS was 4.1 (s.d. 1.6), and for Group MC 5.0 (s.d. 1.3).

5.3.4.3 Series 3 Analyses: Verbal versus Performance IQ

A series of mixed design analyses of variance was carried out, separately on the data collected in Years 1 and 3. There was one between subjects factor (Group i.e. HNS, HS and MC) and one within subjects factor (IQ Type i.e. Verbal versus Performance).

In Year 1, there were significant differences between the Verbal and Performance IQs of the Groups ($F[2,55] = 9.84$, $P < .001$). Newman-Keuls tests, together with inspection of Table 5.2, revealed that Group HS scored significantly below both Groups HNS and MC on Verbal and Performance IQs, but that Group HNS did not score significantly below Group MC. There was also a significant effect of IQ Type ($F[1,55] = 27.19$, $p < .001$). Paired comparison t-tests showed that all three subject groups had significantly higher Verbal than Performance IQs ($t[19] = -3.00$, $p < .01$ for Group MC; $t[25] = 2.71$, $p < .05$ for Group HNS; and, $t[11] = 4.47$, $p < .01$ for Group HS). Subject Group did not interact with IQ Type ($F[2,55] = 0.53$, ns).

In Year 3, there were significant differences between the Verbal and Performance IQs of the Groups ($F[2,54] = 9.54$, $p < .001$). Newman-Keuls tests demonstrated that, in the case of the Verbal IQ, Group HS scored significantly below both Groups HNS and MC. For the Performance IQ data, post hoc tests revealed that, consistent with the results of the Series 2 analyses, not only did Group HS score significantly below both Groups HNS and MC, but also Group HNS scored below group MC. The effect of IQ Type was significant ($F[1,54] = 11.33$, $p < .01$). Paired comparison t-tests showed that only Group HNS had a significantly higher Verbal than Performance IQ ($t[25] = 2.59$, $p < .05$), although the difference for Group HS fell just short of significance ($t[11] = 1.99$, $p = .072$). Subject Group did not interact with IQ Type ($F[2,54] = 0.33$, ns).

Finally, the above analyses were repeated for the Year 1 data, but using WPPSI IQ scores based on the subtests common to the two years of the study i.e. the "short" WPPSI Verbal and performance IQs. The results of these analyses were essentially the same as those obtained for the IQ measures based on four Verbal and four Performance subtests, and are summarised in Table 5.3.

Table 5.3 - Summary of Series 3 Verbal versus Performance IQ Analyses for "short" WPPSI

Factor	**F/t**	**d.f.**	**p**
Group	7.48	2,55	$<.001$
Verbal IQ (VIQ)	Group HS significantly below Group MC		
Performance IQ MC	Group HS significantly below Groups HNS and		
IQ Type	40.31	1,55	$<.001$
VIQ > PIQ - MC	5.34	19	$<.001$
- HNS	2.81	25	$<.05$
- HS	4.27	11	$<.01$
Group x IQ Type	0.87	2,55	ns.

5.3.4.4 <u>Series 4 Analyses: Adjusted IQs and their comparison with the hypothesised population mean of 100</u>

Before proceeding with these analyses, it was necessary to adjust the subjects' IQs to take account of time elapsed since the standardisation of the WPPSI and WISC-R tests. Flynn (1984) and Fuggle, Tokar, Grant and Smith (1992) have presented extensive data arguing for a substantial rise in IQ in the general population over the last five decades. In a sample of 333 British children, an increase of eight IQ points on the WPPSI was recorded over an approximate 12-year period, resulting in an estimated rate of increase of 3.8 points per annum (Fuggle et al., 1992). The Full Scale WPPSI IQ reported for their 1987 - 1990 sample of five-year-olds was 113.3, a figure very similar to that obtained by the control sample in this study (111.5). In Flynn's 1984 study, the estimated rate of increase for the WISC-R was reported to be in the region of 0.3 points per annum. In order to obtain a more realistic picture of the IQ levels of the children in this study, adjustments were made according to the recommendations of Flynn and Fuggle et al.

Thus, the children's Year 1 WPPSI IQs were reduced by 8.36 points i.e. 0.38 of a point for each of the 22 years elapsed between the collection of the test's standardisation sample and the collection of the WPPSI data for the present study. The children's Year 3 short WISC-R IQs were reduced by 4.5 points i.e. 0.30 of a point for each of the 15 years elapsed since WISC-R standardisation and the data collection for the present study. The means and standard deviations of these adjusted IQs are given in Table 5.4. The reduction of the IQs necessitated by the time factor adjustments would not of course influence the results of any of the Series 1 - 3 and Series 5 statistical analyses.

The adjusted mean IQs of Group MC were compared to those of the hypothesised population, using a one-sample t-test (Ferguson, 1981). The Verbal IQs in Years 1 and 3 were significantly higher than that of the hypothesised population Verbal IQ (Year 1 Full WPPSI - $t[18] = -2.10$, $p < .05$; Year 1 "short" WPPSI - $t[18] = -2.40$, $p < .05$; Year 3 WISC- R - $t[18] = -2.02$, $p < .05$). The Full WPPSI Performance IQ in Year 1 and the Year 3 WISC-R Performance IQs did not differ from the hypothesised population Performance IQ ($t[18] = 1.54$, ns, and $t[18] = -1.64$, ns, respectively). However, the "short" WPPSI Performance IQ in Year 1 was significantly below the hypothesised IQ ($t[18] = 2.97$, $p < .05$). The Full Scale IQs in Years 1 and 3 did not differ significantly from the hypothesised IQ, except for Year 3 WISC-R IQ (Year 1 Full WPPSI - $t[18] = -1.19$, ns; Year 1 "short" WPPSI - $t[18] = -0.22$, ns; Year 3 WISC-R $t[18] = -2.18$, $p < .05$). In general, the IQ scores of the medical control group resembled those of the normal population, though there was a consistent tendency for Group MC to have slightly inflated Verbal IQs in both Years 1 and 3 than might be expected for the normal population.

Table 5.4 - Adjusted means and standard deviations of the IQ scores obtained in Years 1 and 3 for Groups MC, HNS and HS

	MC	**HNS**	**HS**
Year 1 (Full WPPSI)			
Verbal IQ	105.8 (11.7)	99.6 (15.8)	87.6 (14.5)
Performance IQ	98.6 (11.1)	92.1 (14.1)	76.2 (16.2)
Full Scale IQ	103.1 (11.1)	96.1 (14.2)	81.6 (15.7)
Year 1 (Short WPPSI)			
Verbal IQ	105.8 (10.2)	99.9 (13.7)	91.5 (13.8)
Performance IQ	95.1 (7.0)	93.1 (11.2)	81.1 (11.7)
Full Scale IQ	100.4 (7.5)	96.5 (10.9)	86.3 (12.1)
Year 3 (Short WISC-R)			
Verbal IQ	107.1 (15.4)	103.0 (16.6)	91.0 (17.0)
Performance IQ	103.1 (8.2)	95.3 (10.1)	83.3 (10.4)
Full Scale IQ	105.1 (10.1)	99.1 (11.4)	87.0 (12.1)

Standard deviations are given in parentheses.

To ensure that the apparent decrements in intelligence shown by Groups HNS and HS were genuine effects, and not artifacts of a comparison with an idiosyncratic control group, the IQ measures of the hemiplegic groups were compared to those of the hypothesised population mean.

For Group HNS, there were no differences between the Verbal or Full Scale IQs and the hypothesised mean IQ of 100 in either Years 1 or 3 (Year 1 Full WPPSI Verbal IQ - $t[25] = 0.13$, ns; Year 1 Full WPPSI Full Scale IQ - $t[25] = 1.40$, ns; Year 1 "short" WPPSI Verbal IQ - $t[25] = 0.04$, ns; Year 1 "short" WPPSI Full Scale IQ = 1.64, ns; Year 3 WISC-R Verbal IQ = $t[25] = -0.92$, ns; Year 3 WISC-R Full Scale IQ = $t[25] = 0.40$, ns). However, Group HNS scored significantly below the hypothesised population with respect to all three Performance IQ measures (Year 1 Full WPPSI - $t[25] = 2.86$, $p < .01$; Year 1 "short" WPPSI - $t[25] = 3.14$, $p < .01$; Year 3 WISC-R - $t[25] = 2.37$, $p < .05$).

Finally, Group HS scored significantly below the hypothesised population mean of 100 on all the Verbal, Performance and Full Scale IQ measures from both Years 1 and 3 (Year 1 Full WPPSI Verbal IQ - $t[10] = 2.95$, $p < .01$; Year 1 Full WPPSI Performance IQ - $t[10] = 5.07$, $p < .001$; Year 1 Full WPPSI Full Scale IQ - $t[10] = 4.06$, $p < .01$; Year 1 "short" WPPSI Verbal IQ - $t[10] = 2.13$, $p < .05$; Year 1 "short" WPPSI Performance IQ - $t[10] = 5.59$, $p < .001$; Year 1 "short" WPPSI Full Scale IQ - $t[10] = 1.83$, $p < .05$; Year 3 WISC-R Verbal IQ - $t[10] = 1.83$, $p < .05$; Year 3 WISC-R Performance IQ - $t[10] = 5.57$, $p < .001$; Year 3 WISC-R Full Scale IQ - $t[10] = 3.72$, $p < .01$).

5.3.4.5 <u>Series 5 Analyses: Changes in IQ scores with increasing age</u>

The availability of longitudinal data afforded the opportunity to examine, not only group differences in IQ scores, but also changes in the groups' IQs over time (i.e with increasing age). Analyses of variance, with repeated measures and planned contrasts, were carried out, using only the "short" WPPSI and WISC-R Verbal and Performance IQs.

Repeated measures over time designs are traditionally analysed with mixed-model analysis of variance. O'Brien and Kaiser (1985) discuss a limitation of this approach in that it assumes sphericity (or circularity) among the repeated measures. A consequence of this distributional property is that all variances of the repeated measures are equal and that all correlations between pairs of repeated measures are equal. However, sphericity is commonly violated for most repeated measures. Non-sphericity artificially inflates F values of the main effects and interactions involving within subjects factors; this in turn affects the Type 1 error rate and the power of the test. The alternative method of analysing repeated measures is the **MANOVA** method advocated by O'Brien and Kaiser and described in full in their 1985 paper. Because this method is free of sphericity assumptions and because it allows for possible pre-test (or "time 1") inequalities, this was the method chosen for this analysis, and for all subsequent repeated measures over time analyses in the thesis.

Consistent with the MANOVA approach, the first analysis examined the between groups comparison for Verbal and Performance IQ, using Year 1 and Year 3 average scores (i.e. Year 1 + Year 3 Verbal or Performance IQ / 2); this analysis excluded the effect of change over time. There was a significant difference between Groups in Verbal IQ ($F[2,54] = 4.90$, $p < .05$). Planned contrasts showed that the combined hemiplegic groups (HNS and HS) had significantly lower Verbal IQs than the control group ($F[1,54] = 7.18$, $p < .05$), that Group HS scored significantly below Group HNS ($F[1,54] = 4.73$, $p < .05$), and that Group HS scored significantly below Group MC ($F[1,54] = 9.76$, $p < .01$).

There was a significant difference between Groups in Performance IQ ($F[2,54] = 13.35$, $p < .001$). Planned contrasts revealed that the combined hemiplegic groups (HNS and HS) had lower Performance IQs than the control group ($F[1,54] = 17.83$, $p < .001$), that Group HS scored significantly below Group HNS ($F[1,54] = 14.77$, $p < .001$), and that Group HS scored significantly below Group MC ($F[1,54] = 26.21$, $p < .001$). The results of these analyses, together with the means presented in Table 5.2, clearly demonstrate the deleterious effects of seizures on IQ.

The second analysis in the MANOVA method examined whether the subject groups differed with respect to any changes over time in IQ scores, between Years 1 and 3. The dependent measures were change over time or difference scores i.e. Year 1 minus Year 3 Verbal (or Performance) IQ. The Groups did not differ in their rate of change of Verbal IQ over time ($F[2,54] = 0.43$, ns). However, there were (near) significant differences between Groups in their rate of change of Performance IQ ($F[2,54] = 3.01$, $p = .058$). Planned contrasts showed that the combined hemiplegic groups (HNS + HS) differed significantly from the Group MC ($F[1,54] = 5.69$, $p < .05$), and that, in addition, Group HNS differed from Group MC ($F[1,54] = 5.25$, $p < .05$). The comparison between Groups HS and MC fell just short of statistical significance ($F[1,54] = 3.43$, $p = .069$). Examination of Table 5.2 revealed that the scores of the hemiplegic samples had remained remarkably stable over the two years of the study. Comparison of the two shortened versions of the Performance IQs of both hemiplegic groups (HNS and HS) showed that the IQ had changed by only 1.6 points between Years 1 and 3, whereas there was an increase of 4.1 points in Group MC's Performance IQ from Year 1 to Year 3. It would appear that this increase accounts for the significant change over time effect on Performance IQ.

5.4 Discussion

5.4.1 Hemispheric Side of Insult and IQ

The Series 1 Analyses of the IQ data established that there were no effects of hemispheric side of insult on any aspect of IQ in either Years 1 or 3 of the study. This is a pattern strikingly different to that observed in adults in whom lateralised injury has occurred later in life; left- versus right-hemisphere injury produces selective impairment, with verbal IQ impaired in left-injured adults and non-verbal IQ in right-injured adults (Kase, 1988; Warrington, James and Maciejewski,1986). The present findings provide evidence in support of the equipotentiality of the left and right hemispheres during development such that either may subserve verbal and non-verbal intellectual abilities in the face of early unilateral injury (Lenneberg, 1967). The current findings are in accord with the results of other recent studies that have failed to demonstrate laterality effects when left- and right-lesioned congenital hemiplegic subjects are compared on IQ measures (Levine et al., 1987; Vargha-Khadem et al., 1992)

In the Series of Analyses 2 - 5, the data were collapsed across the variable of hemispheric side of insult. Inspection of the mean IQs in Table 5.2 suggested that the hemiplegic children without seizures tended to have mildly depressed IQs when their scores were compared to those of the medical control group. However, with the exception of Performance IQ, these differences did not achieve statistical significance (see below for a fuller discussion). It was evident that the IQ scores of the seizure-free hemiplegic children were falling well within normal limits; this was true even when their IQs were adjusted to correct for the time elapsed since original test standardisation (Table 5.4). The analyses confirmed the findings of previous studies that have shown that congenital unilateral injury has at most only a mildly depressing effect on IQ when the children's scores are compared to those of an appropriate control group (Aram, Ekelman, Rose and Whitaker, 1985; Aram and Ekelman, 1986; Levine et al., 1987; Vargha-Khadem et al., 1992).

The seizure-free hemiplegic group recorded a significantly lower WISC-R Performance IQ in Year 3 relative to the medical control group. In addition, all the Performance measures of the seizure free-hemiplegics (Years 1 and 3) were below that of the hypothesised population mean of 100. This selective lowering of Performance IQ in cases of early lateralised injury, without seizure accompaniment, has also been observed by Vargha-Khadem et al. (1992). An explanation for the lower Performance IQ may be afforded by the **Cognitive Crowding Hypothesis** (Teuber, 1975). Thus, following early left hemisphere injury, functional reorganisation takes place in such a way that language functions are preserved within the remaining neural space, but at the expense of other aspects of cognitive function e.g. visuospatial abilities. While normal children would be expected to show even and equal levels of verbal and non-verbal ability, this is prevented in hemiplegic children because of the competition for preservation of function within the reduced neural space. The remaining intact regions of the same or contralateral hemisphere may be forced to undergo reorganisation of cognitive functioning. Verbal abilities are prioritised in the competition for neural space, and so are effectively spared, at least at a gross level. However, to accommodate this reorganisation, other skills may be assigned a lower order of priority, and their development arrested or degraded. These relegated skills are typically visuospatial or executive functions (Vargha-Khadem, 1993). Since the Performance IQ of the seizure-free left hemisphere patients was significantly lowered, it is suggested that a degree of **inter**-hemispheric transfer of language functions (from left to right) had taken place, as opposed to there being exclusively **intra**-hemispheric transfer which would not predict a detrimental effect on Performance IQ. In the case of right hemisphere injury, the selective lowering of the Performance IQ is a direct consequence of damage to those regions specialised for visuospatial processing.

An alternative, albeit less theoretically interesting, explanation for the lower Performance IQ of hemiplegic children pertains to the reduced motor abilities resulting from hemiparesis. Successful scoring on Performance tests is heavily reliant on intact, well controlled and rapidly executed motor responses, enabling the child to manipulate the materials (e.g. blocks) deftly and to earn bonus points through completion within specified time limits. Hemiplegic children are not only frequently reduced to using one hand, but there is evidence to show that the "good" hand of hemiplegic children is not as proficient as the preferred or non-preferred hand of normal children in motor activities such as a pointing task (Brown, Schumacher, Rohlmann, Ettinger, Schmidt, and Skreczek, 1989). In addition, Isaacs, Christie, Vargha-Khadem and Mishkin, submitted 1994) have suggested that a reduction in the strength and dexterity of the right hand in children with left hemisphere lesions is associated with the presence of a left-ear listening advantage. The implication is that the left hemisphere injuries of children with a left-ear advantage are greater than those of children with a right-ear advantage, and so possibly encroach on speech and language related areas of the left hemisphere. The result is an enforced transfer of these essential functions to the homologous areas on the intact, right side.

An attempt was made to capitalise on existing data to decide which hypothesis, Cognitive Crowding or Motor Impairment, better explained the lower Performance IQ of the hemiplegic patients. If the Motor Impairment Hypothesis is correct, then scoring the Block Design test purely on accuracy of response and without time bonuses, should result in a disappearance of the Performance decrement for the hemiplegic sample. However, this was not the case. The seizure-free hemiplegic group scored significantly below the medical control group in their Block Design scores, irrespective of whether the scoring procedure took account of time-related bonus points or not. Thus, the impaired performance of the hemiplegic group on the most sensitive Performance subtest remained after controlling for the motor factor. However, it is acknowledged that this analysis was conducted post hoc, and that test instructions given at the time of administration may have biased the children's responses. While it is unlikely that the reduced motor capacity of the hemiplegic children played a significant role in explaining their relative Performance IQ deficit, this conclusion should be regarded as speculative. A direct test is required in order to unequivocally decide between the two competing hypotheses; for instance, one might compare hemiplegic children's performance on a motor-loaded visuospatial task (e.g. Block Design) with their performance on a similar visuospatial task not requiring a motor response (e.g. mental rotation of shapes).

5.4.2 The Deleterious Effects of Seizures

All five analyses provided strong evidence for the view that the presence of seizures has a significant and markedly depressing effect on all components of intellectual functioning. The hemiplegic patients with seizures were impaired not just in comparison to the control group (and the hypothesised population mean), but also in relation to the seizure-free hemiplegic patients. However, it should be borne in mind that it was not possible in the present study to disentangle the relative contributions of seizures versus medication to the IQ decrement. The studies by Sussova et al. (1990) and by Vargha-Khadem et al. (1992) also found that the presence of seizures resulted in severe deleterious consequences for IQ. It was the presence of seizures, not the extent of structural abnormality, which was the critical variable (Vargha-Khadem et al. 1992). The only study which has produced contradictory findings is that of Levine et al. (1987). These authors have suggested that impairments on psychological measures in cases of childhood hemiplegia with epilepsy are related to size of lesion rather than presence of seizures. Vargha-Khadem et al. (1992) have proposed a possible resolution to this apparent contradiction. It is hypothesised that large lesions of either hemisphere sustained in early childhood, provided they are unaccompanied by seizures, lower Performance IQ selectively. On the other hand, severe seizure activity, even in cases of small lesions, selectively lowers Verbal IQ. In general, the present findings support this proposal, although the absence of imaging data in the present study makes it impossible to directly relate extent of lesion to Performance IQ decrement. It is of interest that the pattern of Verbal-Performance IQ discrepancy (favouring Verbal over Performance) seen in the seizure-free hemiplegic group was also evident in the seizure group. In Vargha-Khadem et al's. study, the Verbal and Performance IQs of the patients with seizures were approximately equally depressed. The present findings suggest that the presence of a lateralised insult to either hemisphere results in a selective lowering of the Performance IQ, while a decrement in the **level** of (all) IQ scores is a consequence of seizure (and/or medication) interference.

5.4.3 Change with Increasing Age in the Hemiplegic Samples

The present study does not provide clear evidence to support the findings of Levine et al. (1987) i.e. that hemiplegic children show a slowing down in their rate of cognitive growth and development, evident as an absolute decline in the IQ, as they get older. Indeed, the children in all the hemiplegic groups showed remarkable stability in their IQ scores over the study period. The present study provides stronger evidence than that of Levine et al., for two reasons. First, the Levine et al. study was cross-sectional, and thus offered only indirect evidence of developmental change with increasing age. The present study is longitudinal and so permits the study of the same children's changes with increasing age. Second, Levine et al. made no attempt to analyse, or to control for, the effects of seizures on IQ levels. In the present study, the data for the seizure and seizure-free groups were analysed separately. There were no group differences in change over time. Both the seizure and seizure-free groups showed stability in their IQ levels over the two year course of the study, although in absolute terms the seizure group had significantly lower IQs in both Years 1 and 3. One caution remains in relation to the conclusions drawn about the stability of the hemiplegic subjects' IQ. The children participating in this research were comparatively young and were followed up for only two years in all. It may be the case that unilateral lesioned children need to be evaluated over a longer period of time in order to observe the decline in IQ which Levine et al. have documented. The Cognitive Crowding Hypothesis might lead us to expect that should this deterioration over time exist, it will be far more marked in visuospatial than in language functioning.

5.5 Conclusion

The failure to discover laterality effects, following early unilateral injury, supports the hypothesis of functional equipotentiality. There were few decrements in intellectual functioning, provided the injury was not accompanied by seizures. While the IQs of the hemiplegic groups showed considerable stability over time, there was evidence that Performance IQ functions, even in seizure-free patients, might be selectively impaired in response to competition within the intact neural space. The presence of seizures, in contrast, had a deleterious effect on all aspects of cognitive functioning.

Chapter 6

Hemispheric Specialisation and Language Functioning in Hemiplegic Children

This chapter is to be divided into two sections. The first will describe the results from the handedness and dichotic listening data, while the second section will consider issues pertaining to language attainments of the clinical sample.

6.1 Handedness and Dichotic Listening:

6.1.1 Introduction:

Left-handedness occurs in approximately 10 percent of the population (Oldfield, 1971). Sodium Amytal studies of patients without evidence of early left cerebral damage have demonstrated that 96 percent of right-handers and 70 percent of left-handers have their speech represented in the left hemisphere (Rasmussen and Milner, 1977). The remaining right-handers (i.e. four percent) have right hemisphere speech representation, while the remaining left-handers (i.e. 30 percent) are equally likely to have either right or bilateral speech representation. Early left hemisphere injury, particularly where the lateral convexity is involved, usually leads to a reorganisation of cerebral motor representation, with the result that there is an increased rate of left-handedness in this population (Carr, Harrison, Evans and Stephens, 1993).

The preference for left hemisphere speech representation may be altered if a left hemisphere injury occurs early in life. Rasmussen and Milner (1977) showed that a shift toward right hemisphere dominance after early left-sided injury is most likely to occur if the lesion includes the primary speech zones. Satz, Strauss, Wada and Orsini (1988) have reviewed evidence to show that, following early left hemisphere injury, shifts in lateral preference are of two types: bimodal, involving reorganisation of both speech and handedness, and unimodal, in which speech is reorganised but hand preference maintained. They have proposed that the type of shift that occurs is related to age at injury, with earlier onset resulting in a greater likelihood of bimodal reorganisation. Furthermore, inter-hemispheric speech reorganisation is associated with an early lesion onset, while intra-hemispheric speech maintenance is linked to later lesion onset (Satz et al., 1988).

The intimate relationship between hand dominance and the lateralisation of language implies that a measure of handedness may be seen as providing a useful and non-invasive index of cerebral lateralisation in clinical populations. If an unusually high incidence of left-handedness is found in children with early left-sided damage, particularly when this occurs in the absence of marked familial sinistrality, it suggests that reorganisation has resulted in a tendency towards right hemisphere processing of language. A further behavioural measure of language lateralisation is that of dichotic listening, which has been used to investigate asymmetry of auditory processing and, by implication, hemispheric functional specialisation (Kimura, 1961). When normal adults are subjected to dichotic listening experiments using verbal material, the majority report more accurately from the right ear (Kimura, 1961). Since the auditory system in man is characterised by predominantly crossed connections, it follows that a right-ear advantage is indicative of left hemisphere processing of language. Hiscock and Decter (1988) reviewed evidence to show that most studies of dichotic listening in normal children have confirmed the right-ear advantage, originally demonstrated in adults. Overall accuracy of report tends to be reduced in young children, but the magnitude of the right-ear advantage remains relatively constant.

Studies of dichotic listening in patients with unilateral lesions have aimed to investigate the effects of such lesions in altering the normal functional representations of the cerebral hemispheres. Children who have acquired left hemisphere lesions early in life, at a time when plasticity should permit functional reorganisation, would be expected to show a left-ear advantage if language functions have indeed come to be represented by the right hemisphere. Carlsson, Hugdahl, Uvebrant, Wiklund and VonWendt (1992) found that

78 percent of their CT-confirmed left-hemisphere-injured patients demonstrated a left-ear advantage on a dichotic listening test, in contrast to only 35 percent of normal left-handers. This finding indicated that a transfer of language functioning from the left to the right had taken place in response to left hemisphere injury. Isaacs, Christie, Vargha-Khadem and Mishkin (submitted 1994) studied ear and hand asymmetry in a large sample of hemiplegic children. The presence of a congenital hemiplegia, in the absence of seizures, resulted in a shift of handedness towards the extremes. The presence of a congenital left hemisphere injury led to an alteration of the normal right-ear advantage. The authors proposed that children showing a marked left-ear advantage were likely to have more extensive left hemisphere lesions, encroaching on language-related areas, than those in which the right-ear advantage had been maintained; thus, in the former group, there was an enforced transfer of language functions to the right side. Children with congenital injuries complicated by a seizure disorder showed an overall reduction in accuracy of report but similar, though more exaggerated, patterns of results to those shown in the seizure-free groups were obtained.

6.1.2 Method

6.1.2.1 Subjects:

The clinical features of the study sample are fully described in Chapter 5. To recapitulate, the five subject groups were as follows: Medical Controls, MC, (n = 20); Left Hemisphere Insult without Seizure, LNS, (n = 15); Right Hemisphere Insult without Seizure, RNS, (n = 11); Left Hemisphere Insult with Seizure, L S, (n = 8); Right Hemisphere Insult with Seizure, R S, (n = 4). Of the 20 children in Group MC, 17 were right-handed; consistent with the procedure adopted in the Isaacs et al. (1994) study, only the right-handed control children were included in the analyses. Of the 23 left hemisphere insult cases, 22 (96 percent) were left-handed. All 15 (100 percent) of the right hemisphere cases were right-handed.

6.1.2.2 Materials and Procedure:

Hand preference was quantified on the basis of a questionnaire (adapted from Crovitz and Zener, 1962) that was administered in Year 1 of the study. The subjects were asked to demonstrate which hand they would use to perform each of 18 common actions, some of which were bimanual e.g. holding a dish when wiping. One point was awarded for a clear right-hand response, and five points for a clear left-hand response. Total scores thus ranged from 18 to 90. High scores indicate marked left-hand preference and low scores marked right-hand preference. A score below 30 was considered to be indicative of strong right-handedness, and one over 55 of strong left-handedness (Milner, 1975). Information pertaining to the hand preference of each subject's parents and siblings was also obtained.

In the listening tasks, administered in Year 3 of the study, the children heard sequences of digits recorded on tape by a female speaker; the tapes used were those originally devised by Kimura (1963). The digits were recorded at the rate of about one per second and played back through stereophonic earphones. There were two conditions of presentation, monaural and dichotic (the alternating condition, also featured in Kimura's tape, was not given). The monaural condition, in which digit sequences were presented to one ear at a time, provided information on the children's accuracy of reporting digits under a non-competing condition. Three strings of six digits were presented to each ear, for a total of 18 digits per ear. The children were told before listening to the tape that they would hear digits in one ear at a time, and they were then to report those they could recall in any order. The dichotic condition had the digit sequences presented on two channels simultaneously. Eighteen sets of digits were presented dichotically i.e. simultaneously to the two ears. The initial presentation consisted of just one digit to each ear, increasing to two and then to three. There were six strings at each length, for a total of 36 digits presented to each ear. The children were told that they would hear digits in both ears, and that they were to report as many digits as they could recall in any order.

6.1.3 Results

6.1.3.1 Handedness Data:

Fifty five subjects (17 medical controls and 38 hemiplegic children) completed the Crovitz and Zener Inventory. The mean handedness scores for the five groups are given in Table 6.1.

Table 6.1 Mean handedness scores on the Crovitz and Zener Inventory according to hemispheric side of insult and seizure status (scores range from 18 to 90, low scores indicate strongly right-handed)

Group	Handedness Score
Medical Controls (MC)	25.29 (4.74)
Left/Non Seizure (LNS)	84.27 (16.44)
Right/Non Seizure (RNS)	20.00 (3.69)
Left/Seizure (LS)	86.25 (9.10)
Right/Seizure (RS)	18.00 (0.00)

Standard deviations are given in parentheses.

As expected, the left hemisphere insult groups, LNS and LS, showed high handedness scores that were indicative of marked left-handedness, while the right hemisphere insult groups, RNS and RS, and Group MC, showed low handedness scores that were indicative of marked right-handedness. Of the 15 right hemisphere insult (and right-handed) subjects, nine (i.e. 60 percent) came from families in which both parents were right-handed, and four (i.e. 27 percent) from families in which one parent was left-handed (there was no familial handedness information available for the remaining two children).

Of the 22 left-handed children in the left hemisphere insult group, five (i.e. 23 percent) came from families in which one of the parents was also left-handed. The remaining 17 (i.e. 77 percent) had parents who were both right-handed. This suggests that the high incidence of left-handedness in the left hemisphere insult group was more likely to be attributable to a pathological condition than to a familial predisposition.

Since the handedness scores provided ordinal data, parametric analysis was not permissible. Consequently, a non parametric Kruskal-Wallis one-way analysis of variance (Siegel, 1956) was performed. The difference between the groups was highly significant ($X = 44.40$, $p < .001$). Mann-Whitney U paired comparisons (Siegel, 1956), showed that first, Group MC differed significantly from all four hemiplegic groups ($z = -4.68$, $p < .001$ compared to Group LNS; $z = -2.99$, $p < .01$ compared to Group RNS; $z = -4.05$, $p < .001$ compared to Group LS; $z = -2.96$, $p < .01$ compared to Group RS). It can be seen from Table 6.1 that the hemisphere insult groups showed either significantly higher or lower handedness scores than the medical control group, suggesting that the hemiplegic children have more extreme degrees of hand preference than do the non-hemispheric damaged controls. Group LNS differed significantly from Group RNS in respect of hand preference ($z = -4.40$, $p < .001$). Group LS also differed significantly from Group RS ($z = -2.96$, $p < .01$). Thus marked hemispheric differences in handedness emerged for both the seizure and non-seizure cases. However, there was not a significant effect of seizures on handedness. No difference in handedness scores occurred when Group LNS was compared with Group LS ($z = -0.32$, ns), nor when Group RNS was compared with Group RS ($z = -1.12$, ns).

6.1.3.2 Listening Data

Preliminary screening of the data, conducted prior to the analyses, showed that all the listening scores, for both the monaural and dichotic conditions, were normally distributed.

The IQ analyses in Chapter 5 had shown that the seizure groups had significantly lower IQs than either the seizure-free groups or the medical controls. Even the seizure-free subjects obtained slightly lower IQ scores than the medical controls, although these differences did not achieve statistical significance. Since it was important to know whether any obtained differences on specific cognitive measures constituted specific effects over and above the influence of IQ, WPPSI Full Scale IQ from Year 1 (the most comprehensive IQ measure available) was entered as a covariate in the analyses of results presented in Chapters 6, 7 and 8. It could be argued that it was unnecessary to control for IQ in the listening analyses, since the focus of the study of the listening data was to investigate ear-advantage rather than level of performance. However, since repetition of digits is a reflection of span capacity, it might be expected to correlate moderately highly with IQ. In view of this, and to achieve parity with the procedures adopted in the analyses of the data in subsequent chapters, it was decided to observe the conservative measure of entering WPPSI Full Scale IQ (Year 1) as a covariate in the analyses of the listening data also.

<u>Monaural Condition</u>:

Data for this condition were supplied by 29 of the hemiplegic children (10 children from Group LNS, 10 from Group RNS, six from Group LS, and three from Group RS) and 15 children from Group MC.

A series of 2 x 2 analyses of covariance was conducted, with hemispheric side of insult and seizures as the independent variables. The dependent variables were the number of digits recalled from the left and right ears separately. The data for the hemiplegic samples, LNS, RNS, LS and RS were entered into the analyses (Group MC was excluded). There was no main effect of hemispheric side (left-ear recall - $F[1,24] = 0.97$, ns; right-ear recall - $F[1,24] = 0.97$, ns). Nor was the main effect of seizures significant (left-ear recall -$F[1,24] = 0.04$, ns; right-ear recall - $F[1,24] = 1.11$, ns). The interaction of hemispheric side with seizures also failed to reach significance (left-ear recall - $F[1,24] = 0.28$, ns; right-ear recall $F[1,24] = 0.17$, ns).

A second series of analyses of covariance with repeated measures examined the relationship between ear (left- versus right-ear recall) and hemispheric side of insult. Since there was no effect of seizure nor an interaction of hemispheric side with seizures, the hemiplegic groups were collapsed across the variable of seizures. Group MC was also included in this analysis. There were no differences in performance between Groups ($F[2,40] = 0.19$, ns), nor were more digits recalled from one ear or the other ($F[1,41] = 3.44$, ns). The interaction of Group with Ear Side failed to achieve significance ($F[2,41] = 1.82$, ns).

Dichotic Condition:

Thirty hemiplegic children (11 children from Group LNS, 10 from Group RNS, six from Group LS, and three from Group RS), and 15 children from Group MC supplied data for the dichotic listening condition. The three dependent measures were: total number of digits correctly reported from each ear (left and right, separately), and a laterality coefficient. The latter score provided a measure of the distribution of responses between ears, independent of accuracy (Marshall, Caplan and Holmes, 1975). When overall accuracy was 50 percent or more, the total number of digits correctly reported from the left ear was subtracted from the total number correctly reported from the right ear; this difference score was then divided by the total number of errors. When accuracy was below 50 percent, the denominator used in the ratio was total number correct. The resulting laterality coefficients had a range of values extending from +1 (maximum right-ear preference) to -1 (maximum left-ear preference). The means and standard deviations of these scores according to Group are given in Table 6.2.

Table 6.2 - Dichotic Listening Data - Means and standard deviations of the left and right ear recall scores and laterality coefficients according to hemispheric side of insult and seizure status

Group	Left Ear Recall	Right Ear Recall	Laterality Coefficient
Medical Controls (MC)	14.80 (6.47)	23.13 (5.82)	0.25 (0.31)
Left/Non Seizure (LNS)	17.36 (5.00)	21.45 (4.72)	0.14 (0.20)
Right/Non Seizure (RNS)	12.40 (5.60)	25.70 (4.24)	0.43 (0.23)
Left/Seizure (LS)	16.50 (9.67)	17.00 (9.08)	0.04 (0.52)
Right/Seizure (RS)	11.67 (8.40)	28.33 (5.03)	0.48 (0.36)

Standard deviations are given in parentheses.

A series of 2 x 2 analyses of covariance examined the effects of hemispheric side (of insult) and of seizures on left- and right-ear recall and the laterality coefficient in the hemiplegic sample (Group MC was excluded). For left-ear recall, there was a nearly significant main effect of hemispheric side ($F[1,25] = 3.76$, $p = .06$). The main effect of seizures did not reach significance ($F[1,25] = 0.10$, ns). Nor was the interaction of hemispheric side with seizures significant ($F[1,25] = 0.00$, ns).

For right-ear recall, there was a significant main effect of hemispheric side ($F[1,25] = 7.95$, $p < .01$). Newman-Keuls tests, and inspection of Table 6.2, revealed that Group LS recalled fewer digits from the right ear than both Group RNS and RS. The main effect of seizures did not attain significance ($F[1,25] = 0.06$, ns). Nor was the interaction of hemispheric side with seizures significant ($F[1,25] = 2.83$, ns).

When the laterality coefficients were analysed, hemispheric side achieved statistical significance ($F[1,25] = 7.53$, $p < .05$). Newman-Keuls tests showed that Groups LNS had a significantly lower mean laterality coefficient than Group RNS (see Table 6.2).

Of interest is the observation that Group LS had the lowest mean laterality coefficient of all the Groups, a figure very close to zero in fact (0.04). However, post hoc tests failed to confirm significant differences between this group and any of the others within the hemiplegic sample. Neither the main effect of seizures, nor the interaction of hemispheric side with seizures reached significant levels ($F[1,25] = 0.15$, ns, and $F[1,25] = 0.43$, ns, respectively). Thus, hemispheric side of insult clearly affected the children's performance on the dichotic listening test with respect to right-ear recall, the laterality coefficient and, very nearly, left-ear recall.

Since there was no effect of seizure nor a significant interaction of hemispheric side with seizure, it was decided to collapse the dichotic listening data across seizure status. Two groups resulted i.e. a left hemisphere insult group (seizure and non-seizure cases, n = 17) and a right hemisphere insult group (seizure and non-seizure cases, n = 13). These groups were compared with the medical control group (n = 15) in a series of one-way analyses of covariance entering the left and right ear recall and laterality coefficient data. (see Table 6.3).

Table 6.3 Mean dichotic listening scores (right-ear recall, left-ear recall and laterality coefficients) according to hemispheric side of insult

Group	Left Ear Recall	Right Ear Recall	Laterality Coefficient
Medical Controls	14.80 (6.47)	23.13 (5.83)	0.25 (0.31)
Left Hemisphere	17.06 (6.70)	19.88 (6.67)	0.10 (0.33)
Right Hemisphere	12.23 (5.93)	26.31 (4.37)	0.44 (0.25)

Standard deviations are given in parentheses.
Right and left ear recall scores are both out of 36.
The laterality coefficient ranges from -1.00 to +1.00.

The Groups did not differ in left-ear recall ($F[2,41] = 2.16$, ns). They did, however, differ in right-ear recall ($F[2,41] = 4.18$, $p < .05$); Newman-Keuls tests, and inspection of Table 6.3 revealed that the right hemisphere insult group recalled significantly more digits from the right ear than did the left hemisphere insult group. The Groups also differed in the laterality coefficient ($F[2,41] = 4.09$, $p < .05$); once again, post hoc tests, and inspection of Table 6.3, showed that the right hemisphere insult group had a significantly higher laterality coefficient than the left hemisphere group, indicating a greater tendency towards right-ear preference in the former group. The scores for the medical control sample on all three measures were in between those of the right and left hemisphere insult groups.

An analysis of covariance with repeated measures examined the relationship between ear side and hemispheric side of insult in the three groups. There was no effect of Group ($F[2,41] = 0.30$, ns). However, there was a main effect of Ear Side ($F[1,42] = 30.48$, $p < .001$); inspection of the means in Table 6.3 showed that there was a strong tendency for more digits to be recalled from the right ear than from the left ear. The interaction of Hemispheric Side with Ear Side was also significant ($F[2,42] = 4.54$, $p < .05$). This interaction was explored further using t-tests for related means. Both the right insult and control groups recalled significantly more digits from the right than the left ear ($t[12] = -5.99$, $p < .001$, $t[14] = -3.20$, $p < .01$, respectively). However, there was no difference in ear preference for the left insult group ($t[16] = -1.03$, n.s.).

6.1.4 Discussion

Cerebral motor reorganisation was demonstrated clearly in the hand preferences of the hemiplegic children. The incidence of left-hand preference, which is about 10 percent in the normal population, increased to 96 percent in the left hemisphere insult cases. In the right hemisphere insult cases, there was a 100 percent incidence of right-handedness i.e. a greater incidence than in the normal population. The tendency for handedness to be shifted towards the extremes in hemiplegic children has also been demonstrated in the large scale study conducted by Isaacs et al. (1994).

The results of the monaural listening condition showed that there were no significant differences between the hemiplegic and control children in the ability to report verbal material accurately under a non-competing condition i.e. there was no decrement in auditory perceptual processing in either ear. Isaacs et al. reported similar findings for their seizure-free hemiplegic groups. However, they did observe an impairment in accuracy of responding in the monaural condition for their seizure groups. The failure of the present study to replicate this finding could be explained by the sample size of the seizure cases, which was very much smaller than in the Isaacs et al. study.

Significant differences between the left and right hemisphere insult groups were obtained on the dichotic listening condition. The left hemisphere group reported roughly equal numbers of digits from the right and left ears. In this group, right-ear recall was significantly poorer than that of the right hemisphere group. The left hemisphere group also showed a lower laterality coefficient than the right hemisphere group. On the other hand, the right hemisphere insult group reported significantly more digits from the right than the left ear, with the pattern of scores being indicative of a marked right-ear preference. In general, the scores of the medical control group fell between those of the hemiplegic groups. Although the differences between the control and the hemiplegic groups did not achieve statistical significance, there was a tendency for the left and right hemisphere insult groups to show greater extremes of scoring than the control group. A demonstrable shift away from the usual right-ear advantage in the left hemisphere insult group was also reported in the Isaacs et al. study. They obtained a small left-ear advantage for their seizure-free left hemisphere group, whereas in the present study the laterality coefficient for the left hemisphere insult cases remained positive, albeit close to zero (0.13 for the seizure-free cases, and 0.04 for the seizure cases). The results for the left hemisphere insult group support the view that a degree of cerebral reorganisation of language had taken place in some, if not all, the children. Early left hemisphere injury resulted in left-handedness and a reduced right-ear advantage, this being indicative of a tendency towards greater right hemisphere processing of language. Although the differences did not achieve statistical significance, inspection of the laterality coefficients suggested that the right hemisphere shift was greater in the seizure than non-seizure left hemisphere cases.

Isaacs et al. have proposed that the more extensive the left hemisphere lesions, the greater the enforced transfer of language functions to the right side, with the result that the right-ear advantage is either very markedly reduced, or else there is a shift to a left-ear advantage. It could be hypothesised that the seizure patients in the present study had more extensive lesions than the non-seizure patients (although, in the absence of radiological data, this cannot be confirmed). If this were the case, then the left hemisphere patients would be expected to have reduced neural capacity in the left hemisphere for language processing, with the result that these important functions would have to be subserved by the right hemisphere.

6.2 Language Functioning:

6.2.1 Introduction

The language skills of hemiplegic children have been extensively studied by Aram and her colleagues (see Chapter 4). The evidence in general supports the view that the right hemisphere is capable of supporting at least gross language functions; to what extent it is able to process more subtle and specific aspects of language functioning remains a matter of some controversy and dispute. In the present study, the hemiplegic children were given a range of receptive and expressive language tests during the three years of data collection. The effects of hemispheric side of insult and of seizures were studied. Only one measure, a receptive vocabulary test, was given more than once, so there was less scope for evaluating the development (or change) in language skills over time (i.e. with increasing age) than there was for the other measures being studied.

6.2.2 Method

6.2.2.1 Subjects:

The clinical features of the subjects and their group allocation are fully described in Chapter 5.

6.2.2.2 Materials and Procedure:

Year 1:

Three language tests were administered in Year 1: the long form of the British Picture Vocabulary Test (Dunn, Dunn and Whetton, 1982), the Test of Reception of Grammar, TROG (Bishop, 1982), and the Bus Story Test (Renfrew, 1969).

The BPVS provided a measure of each child's receptive vocabulary. He or she selected out of four pictures the one that most accurately depicted the meaning of the single word spoken by the examiner. The total number of correct responses (out of 150) was the measure used in the analyses.

The TROG assessed the children's understanding of increasingly lengthy and grammatically complex sentences. For each item, the child selected from four pictures the one that most accurately depicted the meaning expressed in the examiner's utterance. Grammatical structures sampled included singular/plural pronouns and reversible active/passive constructions. In the present study, the score used in the analyses was the number of correctly selected pictures (out of a total of 80).

In the Bus Story Test, the child followed a story read to him or her by the examiner using a picture book. He or she was then instructed to tell the story back to the examiner, using the pictures in the book as a guide. The child was scored for the number of correct ideas contained in the re-telling of the story (out of a total possible score of 54), and for the mean length of sentence utterance.

All three tests were administered according to the procedures specified in their respective manuals, including observance of criteria for discontinuance (where relevant).

Year 2:

The first of three different language tests employed in Year 2 was a test of Picture Naming (Snowling, Wagtendonk and Stafford, 1988), a modified version of the Boston Naming Test. The task required the timed naming to confrontation of 40 pictures of varying degrees of difficulty, ranging from easy items like "banana" and "elephant" to difficult items like "gondola" and "aquarium". If the child failed to name the picture within an acceptable time period (up to approximately 30 seconds), he or she was provided with a "phonic" cue, specifically the initial sound of the required word. If that failed to elicit a response, a "semantic" cue was given i.e. a definition of the required word, usually in terms of its function. Spontaneous correct naming earned a score of three points, naming to a phonic cue two points, and naming to a semantic cue one point, making for a total possible score of 120.

The second language test was Formulated Sentences from the Clinical Evaluation of Language Fundamentals - Revised, CELF-R (Semel, Wiig and Secord, 1987), in which the child was asked to formulate a sentence containing one or more words specified by the examiner, with the help of a picture cue. The score used in the analyses reflected the grammatical complexity and completeness of the child's utterance, and was derived in accordance with the scoring procedures described in the CELF-R manual, with a total possible score of 60.

The final test was Word Fluency. The child was asked to name as many words as he or she could beginning with the sound "s", within a 60 second time period. This procedure was repeated for a second sound, "f". The final score was the total number of words given by the child to both letter sounds.

Year 3:

The BPVS Test was administered again, as in Year 1.

6.2.3 Results

Preliminary screening of the data indicated that all the language measures had acceptably normal distributions; consequently, raw scores (as described above) were used, without the need for logarithmic transformation. Two Medical Control subjects were excluded from the analyses performed on the Word Fluency data (Year 2), because they both had unusually inflated scores i.e. they were outliers. One child had Turner's Syndrome, a genetic disorder often associated with elevated verbal fluency (Temple and Carney, 1993). The other had Aarskog Syndrome.

6.2.3.1 Rationale of Analyses

Three series of analyses were conducted. The **Series 1 Analyses** investigated the effects of hemispheric side of insult and of seizures on the hemiplegic children's language functioning (the Medical Control group was excluded from these analyses). In the **Series 2 Analyses**, differences between the hemiplegic children and the medical controls were studied. The final **Series 3 Analyses** examined change in receptive vocabulary (as measured by the BPVS) between Years 1 and 3 of the study.

WPPSI Full Scale IQ was entered as a covariate in all of these analyses. This enabled an appraisal of the specific effects of seizures on language performance, over and above those explicable in terms of the lower IQ of the seizure samples. Significant results are reported in the text, and non-significant results summarised in Appendices 6.1 to 6.3.

6.2.3.2 Series 1 Analyses - The effects of hemispheric side and of seizures on language functioning in the hemiplegic sample

The scores obtained by all four groups of hemiplegic subjects (Groups LNS, RNS, LS and RS) were entered into a series of 2-way analyses of covariance assessing the effects of hemispheric side of insult, seizures and their interaction on language test performance, separately for each year of the study. The means and standard deviations of the language test scores according to group are given in Tables 6.4 through 6.6. The results from each year will be described in turn. Non-significant results are reported in Appendix 6.1.

In **Year 1**, the children's scores on the TROG, the BPVS and the Bus Story tests were the dependent measures (Table 6.4). The only significant effect to emerge was an interaction of hemispheric side with seizures on performance on the BPVS test ($F[1,33] = 7.83$, $p < .01$). Newman-Keuls tests showed that the children in Group LS scored significantly below those in Groups LNS and RS.

Table 6.4 - Language Data - Means and standard deviations of the language measures in Year 1 according to Group

			Group		
Test	**MC**	**LNS**	**RNS**	**LS**	**RS**
BPVS (/150)	38.85	44.13	41.82	30.25	42.50
S.D.	10.87	8.37	12.51	9.05	10.50
TROG (/80)	51.50	51.53	51.00	40.87	48.00
S.D.	12.73	10.73	14.41	13.12	20.20
Bus St Info (/54)	26.00	21.93	20.18	16.50	18.75
S.D.	7.12	8.36	7.53	9.86	9.03
Bus St Sent Length	8.60	6.87	7.09	5.94	6.87
S.D.	1.78	2.03	2.34	1.15	2.69

S.D. - Standard deviation.
BPVS - British Picture Vocabulary Test. TROG - Test of Reception of Grammar.
Bus St - Bus Story Test: Info - Information score, Sent Length - Average Sentence Length.

In **Year 2**, the children were given the CELF-R Formulated Sentences Test, Word Fluency and Picture Naming (Table 6.5). For the Formulated Sentences test scores, there was a significant effect of seizures ($F[1,33] = 4.97$, $p < .05$). Moreover, the hemispheric side of insult interacted significantly with the effects of seizures ($F[1,33] = 7.49$, $p < .05$). Newman-Keuls tests demonstrated that again Group LS scored significantly below both Groups LNS and RS on the Formulated Sentences measure. None of the other analyses resulted in significant effects.

Table 6.5 - Language Data - Means and standard deviations of the language measures in Year 2 according to Group

Test	MC	LNS	RNS	LS	RS
Pict Naming (/120)	63.80	61.80	60.00	49.87	46.75
S.D.	17.61	16.75	16.52	18.24	19.53
Form Sent (/60)	23.30	24.80	20.91	9.37	19.75
S.D.	6.70	9.68	10.10	5.50	7.27
Word Fluency *	4.94	7.60	6.36	2.62	6.25
S.D.	4.17	4.26	5.97	3.66	5.85

Pict Naming - Picture Naming.
Form Sent - Formulated Sentences.
* - Number of words given by child.

In **Year 3** only the BPVS was given, with no significant effects emerging (Table 6.6).

Table 6.6 - Language Data - Means and standard deviations of the BPVS scores in Year 3 according to Group

	MC	LNS	RNS	LS	RS
BPVS	60.16	60.87	61.64	49.75	55.00
S.D.	12.54	9.94	14.25	16.49	22.67

6.2.3.3 Series 2 Analyses - The effects of hemispheric side of insult and of seizures on language functioning, in comparison with the medical control group

First, analyses were conducted that aimed to explore further whether there were differences between the hemiplegic children and the medical control subjects on those language measures for which **non-significant** results had been reported in the Series 1 Analyses i.e. TROG and Bus Story in Year 1, Picture Naming and Word Fluency in Year 2, and BPVS in Year 3. Since no effect of hemispheric side had been demonstrated for these measures, it was considered legitimate to collapse across this variable. Three groups of children were compared in a series of analyses of covariance, with planned contrasts i.e. hemispheric injury without seizures (Group HNS), hemispheric injury with seizures (Group HS) and medical controls (Group MC). No significant main effects were obtained for any of the language measures during the three years under study.

A further series of analyses was conducted in order to confirm and to explore further the **significant** effect of seizures and of the hemispheric side with seizures interaction evident in the Series 1 Analyses for BPVS in Year 1 and Formulated Sentences in Year 2. Four groups were studied: LNS, RNS, LS and RS.

For BPVS in Year 1, there was a significant main effect of Group ($F[3,33] = 3.11$, $P < .05$). Planned contrasts concentrated on comparing the following Groups: LNS versus RNS, LS versus RS, LNS versus LS, RNS versus RS, and Groups LNS + RNS versus LS + RS. Two of the planned contrasts achieved significance: Group LS scored significantly below Group RS ($F[1,33] = 6.39$, $p < .05$), and also significantly below LNS ($F[1,33] = 6.12$, $p < .05$).

The above pattern of effects was replicated for the Formulated Sentences data. There was a significant effect of Group ($F[3,33] = 4.16$, $p < .05$). The following planned contrasts were significant: Group LS again scored significantly below Group RS ($F[1,33] = 4.90$, $p < .05$), and also below Group LNS ($F[1,33] = 11.20$, $p < .01$).

These findings for Year 1 BPVS and for Year 2 Formulated Sentences were consistent with those obtained in the Series 1 Analyses in pointing to the disadvantageous effects on language when seizures are present in children with left hemisphere insults. Inspection of Table 6.3 showed that Group LS was particularly disadvantaged on both language measures relative to Group RS and relative to Group LNS.

It was considered important to compare the groups on the above measures in relation to the medical control group as well. Performance on the BPVS in Year 1 and Formulated Sentences in Year 2 was studied in the following three groups: LNS, RNS and MC.

There was a main effect of Group for the BPVS scores ($F[2,42] = 4.20$, $p < .05$). Planned contrasts of the following group pairs were conducted: LNS versus RNS, MC versus LNS, MC versus RNS, and Groups LNS + RNS versus MC. The contrasts showed that, first, Group MC scored significantly below Group LNS ($F[1,42] = 8.53$, $p < .01$), and that Group MC also scored significantly below the combined hemiplegic Groups, LNS + RNS ($F[1,42] = 6.46$, $p < .05$).

The Formulated Sentences data were analysed in the same way, but no significant results were obtained.

6.2.3.4 Series 3 Analyses - BPVS and change over time (Years 1 and 3)

The final analyses of the language data entailed a MANOVA repeated measures analyses of covariance, with planned contrasts, of the BPVS data collected in Years 1 and 3 of the study (see Chapter 5.3.4.5 for the rationale). The first of two analyses comprised a between groups comparison using the subjects' average scores (Year 1 + Year 3 BPVS scores /2), and excluded the effect of time. The second analysis addressed whether the subject groups differed in respect of their development of vocabulary over time i.e. with increasing age. The dependent measure was a change over time or difference score i.e. Year 3 minus Year 1 BPVS scores.

The average and change scores for the BPVS data in Years 1 and 3 were analysed first for the subjects in Groups RNS, LNS and MC. The analyses of the average scores essentially replicated the results of earlier analyses. There was a significant main effect of Group ($F[2,41] = 4.00$, $p < .05$). Planned contrasts concentrated on the following group pairs: LNS versus RNS, LNS versus MC, RNS versus MC, and LNS + RNS versus MC. Group MC scored significantly below Group LNS ($F[1,41] = 7.89$, $p < .01$) and below the combined Groups LNS + RNS ($F[1,41] = 6.35$, $p < .05$). The groups did not differ with respect to their change over time scores i.e. there was no difference between the groups in terms of their rate of change or improvement over time.

The analyses with repeated measures were also carried out for the BPVS average and change over time scores in the four hemiplegia groups, LNS, RNS, LS and RS. There were no significant differences between the groups with respect to either the average or the change scores.

6.2.4 Discussion

In general, the results of the language analyses showed that there were no marked or pervasive detrimental effects of hemispheric side of injury on language development, other than those that might be accounted for by the IQ differences reported in Chapter 5. In other words, the results tended to support the view that the two hemispheres show equipotentiality for language processing, at least in those groups with early injuries uncomplicated by seizures. The observation that the children in the medical contol group were performing below the level of the left hemisphere group without seizures on the BPVS Year 1 and on the BPVS average scores was thought to be an artifactual and sample-specific result.

However, there was a series of robust and consistently significant results that indicated that one particular hemiplegic group, the left hemisphere insult group with seizures, was encountering exceptional difficulty in language functioning. This group was significantly impaired relative to the right hemisphere group with seizures and relative to the left hemisphere group without seizures on the BPVS test in Year 1 and on the Formulated Sentences test in Year 2 (Series 1 and 2 Analyses). These results were obtained even when the analyses controlled for IQ, so clearly there was a deficit additional to that accounted for by the lower IQ of the seizure cases, and the deficit was in turn specific to the left hemisphere insult group.

Children with early hemispheric injury, provided they are seizure-free, develop apparently normal language functioning, at least at a gross level. This is true even for children with left hemisphere insults who would be expected to undergo a substantial degree of language reorganisation. Thus, the early injured brain is capable of a remarkable capacity for reorganisation and, therefore, for sparing of language function.

However, it seems likely that the presence of seizures, irrespective of hemispheric side of injury, interferes with cognitive functioning as evidenced by the generalised decrements in IQ found in those patients whose hemispheric insults were complicated by seizures (Chapter 5). Moreover, it appears that children with left hemisphere insults accompanied by seizures are particularly disadvantaged in terms of their language processing. This impairment is over and above the decrement in IQ level, and may consequently reflect the interference of seizures with the process of hemispheric reorganisation. The findings in the present study point to the likelihood that seizures, or possibly even medication, disrupt the capacity of the left-hemisphere-injured brain to optimally reorganise itself. The right hemisphere may, under certain (stable and optimal) conditions, successfully take over the processing of language skills, as evidenced by the language sparing of the seizure-free left hemisphere patients. However, seizures appear to interfere with what is usually a successful reorganisation process.

It as yet premature to draw conclusions about the specific mechanisms through which seizures impair selective aspects of spoken language development in left hemisphere injured patients. However, the present results might lead one to speculate that there are two possible mechanisms of interference. The first draws on the findings from the dichotic listening data. It was found that the left hemisphere group with seizures recorded the lowest laterality coefficient in the dichotic listening test, an observation consistent with there being a greater degree of right hemisphere processing of language in this than in any other group. In view of the hypothesised link between a shift towards left-ear advantage and the presence of more extensive lesions (Section 6.1.4), it could well be the case that these patients had larger and consequently more severe left hemisphere lesions. The children with left hemisphere insults and seizures would, therefore, be expected to have less neural space in the left hemisphere for language processing. Consequently, an enforced shift towards right hemisphere processing of language takes place. It is tempting to speculate that the left hemisphere patients with seizures are processing language either bilaterally or in the right hemisphere, while some of the seizure-free left hemisphere patients are able to continue to use the left hemisphere for processing language. Visual inspection of the patients' laterality coefficients did not strongly support this hypothesis; there was in fact enormous variability in the scores, a finding that is perhaps not surprising bearing in mind the observed low reliability of dichotic listening techniques (see Chapter 4.2). However, the group findings lead one to speculate that, in left hemisphere patients with seizures, the neural capacity for processing language in the left hemisphere is reduced, while the ability of the right hemisphere to subserve these functions through reorganisation is disrupted by seizures.

An alternative, though perhaps not mutually exclusive explanation, of seizure interference effects makes no assumptions about extent of lesion or degree of right hemisphere shift. It is quite likely that seizures interfere not only with left hemisphere function, but, due to "spread" effects, disrupt right hemisphere function also. The result is a reduced neural capacity of both hemispheres to subserve language function.

6.3 Conclusions:

The children with hemispheric injuries showed greater extremes of handedness, and of ear preference (on a dichotic listening test) than a control group. A demonstrable shift away from the usual right-ear advantage found in the left hemisphere insult group implied that cerebral reorganisation of language had taken place, that would suggest some degree of right hemisphere processing of language. Language functions were not significantly impaired in children with either right or left hemisphere insults, provided their injuries were not accompanied by seizures. The left hemisphere insult group with seizures, however, showed selective language deficits that were not explicable in terms of their lower IQ. These finding were discussed in relation to possible mechanisms through which seizures might disrupt language reorganisation processes.

Chapter 7

Phonological Awareness, Reading, Spelling and Arithmetic Skills in Hemiplegic Children

7.1 Introduction

A great deal of evidence has accumulated over the last 10 - 15 years demonstrating the powerful relationship between phonological awareness and the acquisition of early reading and spelling skills (see Chapter 1 for a full discussion).

Phonological skills and their relation to literacy development have been studied extensively not only in normal populations, but also in certain clinical populations, notably children suffering from developmental dyslexia. Group and individual case studies have shown that the majority of dyslexics have poor phonological awareness and consequently find it hard to adopt systematic phonic strategies in reading and spelling (see Chapter 1.4.5).

There is a dearth of studies pertaining to phonological processes and reading development in paediatric neurological populations. Yet, as Patterson and Vargha-Khadem (1991) point out, the study of neurological patients may provide important information about the strength of the phonology-reading relationship. They have argued that, if brain-lesioned children learning to read in a patently atypical way still show an association between levels of skill in reading and in phonological ability, this implies that the relationship between these cognitive functions is strong and meaningful and is presumably, therefore, relatively impervious to disruption.

The extensive studies of congenital hemiplegics by Aram and her colleagues have concentrated on language (usually syntactic) processes rather than on phonological and literacy or numeracy skills (See Chapter 4.5). There is, however, one study that employed a standardised educational measure i.e. the Woodcock-Johnson Psycho-educational Battery (Aram and Ekelman, 1988). The results failed to report any differences in hemispheric side or any specific patterns of performance, although the hemiplegic sample did score marginally below the matched controls on all the subtests. Phonological awareness and its relation to the development of literacy skills has not yet been studied in children having unilateral lesions.

Patterson, Vargha-Khadem and Polkey (1988) did, however, have the opportunity to study phonological processes and literacy development in two teenage girls who had undergone complete hemispherectomy (one left, one right) for late-onset intractable epilepsy. Both of these subjects had developed normal language and had learned to read before developing Rasmussen's Encephalitis at 10 and 13 years of age. The reading performance of the right-hemidecorticated patient was relatively unaffected, while that of the left-hemidecorticated patient was severely impaired. Not only did this patient have poorly developed reading levels but she also demonstrated marked phonological processing difficulties; she could not rhyme, nor manipulate phonemes within words, and she could not read nonwords. Thus, the strong connection between phonological processing and level of reading skill, evident in normal populations, held up for this neurological case also. It was further concluded that fine phonological processing is a skill that is predominantly subserved by the left hemisphere. However, it needs to be recognised that this conclusion pertains to late-acquired injury in previously neurologically intact individuals. It could be argued that the failure of the left-hemidecorticated patient to reinstate previously appropriate phonological and reading skills might have been due to the isolated right hemisphere's inability to support phonological skills following a late onset injury i.e. the right hemisphere's functions may by then have become relatively fixed so that there was little room for plasticity and consequent functional reorganisation. That is not to say of course that when a left-sided injury occurs during the pre- or peri-natal period the right hemisphere could not reorganise itself in such a way that phonological processes, normally lateralised to the left, are successfully represented in either the right hemisphere or in the remaining intact regions of the left hemisphere.

The present study provided an opportunity to explore the development of phonological awareness, reading, spelling and arithmetic skills in hemiplegic children investigated longitudinally over a two-year period. Chapter 7 addressed three main issues. First, the effects of hemispheric side of insult and of seizures on phonological processes, reading, spelling and numeracy in each year were studied through a series of cross-sectional analyses. Second, the availability of repeated measures permitted the investigation of the various groups' development of phonological, literacy and arithmetic skills over time. Finally, it was of interest to determine whether the relatively independent phonological awareness factors, **rhyming** and **segmentation**, uncovered in a normal population (Chapter 2) would be similarly observed in a neurological population. In Chapter 8, the relationships between the hemiplegic children's phonological and memory skills and their reading and spelling attainments will be considered, with particular reference made to the model of early literacy development that was generated in Chapter 2.

7.2 Method

The subjects, design and procedure are fully described in Chapter 5.

7.2.1 Materials:

The phonological awareness measures and attainment tests were the same as those administered to the normal group, as described in Chapter 2.

Briefly, in **Year 1**, the children were given tests of rhyme detection and production, phoneme identification, phoneme deletion, auditory/verbal memory (WISC-R Digit Span) and visual memory (Goulandris Test of visual memory for letter-like forms), together with attainment tests of letter name knowledge and single word reading (BAS).

In **Year 2**, these tests were repeated, with the addition of a sound blending test (ITPA), and of tests of prose reading (Neale) and spelling (Schonell).

In **Year 3**, all of the tests given in Year 2 were readministered, along with two tests of arithmetical attainment, one oral (WISC-R) and one written (an extension of the Basic Number Screening Test).

The tests, their administration and scoring procedures are fully described in Chapter 2.

7.3 Results

The results will be reported separately and in turn for the phonological awareness and the attainment tests.

7.3.1 The Phonological Awareness Measures

Preliminary scrutiny of the data revealed that two of the measures, phoneme deletion in Year 1 and rhyme detection in Year 3, necessitated logarithmic transformations, owing to a floor effect in the case of the deletion test and a ceiling effect with respect to the rhyme detection measure. These transformed variables were used in the analyses. It was also decided to exclude two of the Medical Control subjects from the analyses. One of these subjects had Turner's Syndrome, which recent research has shown to be associated with unusually elevated literacy, including phonological, skills (Temple, 1993). Data screening, conducted along the lines described in Chapter 5, demonstrated that this subject had high outlier scores on rhyme production in Year 1 and on sound blending in Year 2. A second subject, a child with Aarskog Syndrome, had elevated outlier scores on rhyme production and phoneme identification in Year 1 and on rhyme production in Year 2. In view of this, and since this subject was absent for all of the Year 3 testing, it was decided to exclude him from the analyses.

7.3.1.1 Rationale of Analyses:

Five groups of subjects were studied: LNS (left hemisphere insult without seizure disorder), RNS (right hemisphere insult without seizure disorder), LS (left hemisphere insult with seizure disorder), RS (right hemisphere insult with seizure disorder) and MC (Medical Controls).

Three series of statistical analyses of the phonological awareness data were conducted:

Series 1 investigated the effects of hemispheric side of insult and of seizures on the phonological awareness measures in all four hemiplegic groups i.e. LNS, RNS, LS and RS (but excluding Group MC);
Series 2, included the medical control group, and permitted the study of the groups' phonological awareness development, through repeated measures analyses, over the two years of the study;
Series 3 analyses subjected the phonological awareness data to Principal Components Analyses in order to determine whether the two factors, rhyming and segmentation, that emerged so clearly for the normal group were also evident for the clinical samples.

Since it was important to know whether group differences in phonological awareness constituted specific effects over and above the influence of IQ, it was necessary to enter Year 1 WPPSI Full Scale IQ as a covariate in both the Series 1 and 2 analyses.

Significant results are reported within the chapter, while non-significant results are summarised in Appendices 7.1 through 7.3.

7.3.1.2 Series 1 Analyses - The effects of hemispheric side of insult and of seizures on phonological awareness

The data from all four groups of hemiplegic subjects were entered into a series of 2-way analyses of covariance addressing the effects of hemispheric side of insult and seizures on phonological awareness test performance, separately for each of the three years of the study. The means and standard deviations of the phonological awareness scores according to group are given in Tables 7.1 to 7.3. Non-significant results are reported in full in Appendix 7.1. The results from each year will be described in turn.

In Year 1, the phonological measures were those of rhyme detection, rhyme production, phoneme identification, and phoneme deletion (Table 7.1). After controlling for the effect of IQ, there were no significant main effects of hemispheric side nor of seizures. Nor did the interaction of hemispheric side of insult with seizures achieve significance.

Table 7.1 - Phonological Awareness Data - Means and standard deviations of the phonological awareness measures in Year 1 according to Group

			Group		
	MC	**LNS**	**RNS**	**LS**	**RS**
Rhyme Detect (/10)	6.90	5.67	5.45	3.50	3.25
S.D.	3.23	3.04	2.91	2.56	1.26
Rhyme Product *	1.85	1.87	1.18	0.12	0.25
S.D.	2.80	3.09	1.33	0.35	0.50
Ph Identific (/8)	3.40	3.47	3.36	2.12	4.24
S.D.	2.80	3.04	2.77	2.59	3.50
Ph Deletion (/10)	0.45	0.60	0.27	0.25	0.00
S.D.	1.19	1.59	0.65	0.46	0.00

S.D. - Standard deviation.

Ph - Phoneme, Detect - Detection, Product - Production, Identific - identification.

* - Number of correct rhymes produced.

In Year 2, the phonological awareness tests studied were rhyme detection, rhyme production, phoneme identification, sound blending and phoneme deletion (Table 7.2). The only measure that resulted in statistically significant findings was that of rhyme production. There was a significant effect of hemispheric side of insult ($F[1,33] = 5.14$, $p < .05$). Moreover, the hemispheric side of insult significantly interacted with the effects of seizures ($F[1,33] = 9.08$, $p < .01$). Newman-Keuls tests showed that Group RNS scored significantly below Group LNS. The reverse pattern seemed to be evident in the seizure sample i.e. that Group LS scored below Group RS, although post hoc tests failed to reach significance.

Table 7.2 - Phonological Awareness Data - Means and standard deviations of the phonological awareness measures in Year 2 according to Group

			Group		
	MC	**LNS**	**RNS**	**LS**	**RS**
Rhyme Detection	7.55	7.80	7.00	6.38	6.75
S.D.	2.44	2.91	3.07	3.58	2.50
Rhyme Production	3.20	4.27	1.18	1.50	3.25
S.D.	4.15	3.49	1.40	2.51	3.59
Ph Identification	5.50	4.87	4.64	3.38	3.75
S.D.	3.19	3.02	3.50	2.26	2.99
Ph Deletion	4.15	3.47	2.09	1.37	3.25
S.D.	4.15	4.00	3.42	2.67	4.72
Blending (/32)	15.15	14.73	12.45	12.25	11.75
S.D.	6.65	6.98	4.48	4.86	4.71

In Year 3, the phonological awareness tests were the same as those administered in Year 2 (Table 7.3). After controlling for the effects of IQ, there were no significant effects of hemispheric side of insult, nor of seizures. Nor did hemispheric side of insult interact with the effects of seizures.

Table 7.3 - Phonological Awareness Data - Means and standard deviations of the phonological awareness measures in Year 3 according to Group

	Group				
	MC	**LNS**	**RNS**	**LS**	**RS**
Rhyme Detection	8.21	8.53	7.18	6.75	7.00
S.D.	2.74	2.97	3.19	3.88	2.94
Rhyme Production	6.37	4.87	4.18	2.50	4.75
S.D.	4.56	3.09	3.95	2.51	5.50
Ph Identification	6.89	6.87	5.82	5.63	5.75
S.D.	2.31	1.73	2.89	2.67	2.87
Ph Deletion	6.00	5.00	4.91	2.63	5.00
S.D.	4.85	4.52	4.35	3.78	5.78
Blending	21.05	18.73	17.91	16.38	11.75
S.D.	7.49	7.57	6.16	5.66	4.57

7.3.1.3 Series 2 Analyses - The development of phonological awareness in hemiplegic children

A series of analyses of covariance with repeated measures and planned contrasts were conducted (MANOVA method, O'Brien and Kaiser, 1985). These examined how the children's phonological awareness abilities developed over the two years of the study. Since previous analyses had confirmed that there were no significant effects of hemispheric side of insult for all measures (other than rhyme production in Year 2), the left and right hemisphere groups were collapsed into one group. Analyses were conducted that examined the performance of the following three groups on the tests of rhyme detection, phoneme deletion and phoneme identification over the three years of the study - medical controls (MC), unilateral hemispheric injury without seizure (HNS) and unilateral hemispheric injury with seizure (HS). The analyses of the rhyme production and sound blending data were restricted to Years 1 and 3 and Years 2 and 3, respectively. IQ was used as a covariate. For each variable, the first analysis looked at the between groups comparison using the children's average scores over the two or three years under study, and excluded the effect of improvement with age. For the measures of rhyme detection, phoneme identification and phoneme deletion, the average scores were calculated as follows: Year 1 + Year 2 + Year 3 scores /3. The second analysis addressed whether the subject groups differed in respect of the development of the specified phonological ability over time i.e. with increasing age. The dependent measures were "change" or difference scores. For the measures of rhyme detection, phoneme identification and phoneme deletion, the difference scores were calculated as follows: Year 2 minus Year 1 scores and Year 3 minus Year 1 scores. No significant results were obtained for either the average or change scores on any of these three measures (see Appendix 7.2).

The sound blending test had been administered in only Years 2 and 3 of the study. The analyses conducted for the sound blending data repeated over Years 2 and 3 produced no significant effects for either the average scores (Year 2 + Year 3 sound blending /2) or change/difference scores (Year 3 minus Year 2 sound blending).

Although rhyme production data were available for all three years of the study, the presence of a significant effect of hemispheric side of insult and a significant interaction of hemispheric side with seizure in Year 2 prevented the collapsing of groups across hemispheric side in that year (Series 1 Analyses, Year 2). Consequently, the analyses with repeated measures were conducted for only the Years 1 and 3 data points. Neither the average scores (Year 1 + Year 3 rhyme production /2) nor the change scores (Year 3 minus Year 1 rhyme production) group comparisons achieved significance.

7.3.1.4 Series 3 Analyses - Principal Components Analyses of the phonological awareness data

The Principal Components Analyses of the phonological awareness data in each year of the study were conducted separately for the medical control and hemiplegic (combined seizure and non seizure) groups. The collapsing of the hemiplegic groups was necessitated by the small group sizes, and justified on the grounds of there being very few statistically significant results emerging from the Series 1 and 2 Analyses of the phonological awareness data. In both groups, only one factor, having an Eigen value greater than 1, emerged for each year. The Eigen Values, variance contribution and the loadings of each of the tests on the single factor in each year of the study are given in Table 7.4. The single factor was termed a Global Phonological Awareness Factor.

The Principal Components Analyses were then repeated for the medical control and hemiplegic groups combined. Once again, a single (Global Phonological Awareness) factor was obtained for each year of the study, in each case having an Eigen value of greater than 1. Table 7.4 summarises the findings of these analyses. The factor scores were saved from each analysis. Analyses of variance were carried out, comparing the five clinical groups, LNS, RNS, LS, RS and MC on the factor scores in each year of the study. No significant differences were obtained (Appendix 7.3).

Table 7.4 - Phonological Awareness Data - Series 3 Analyses - Principal Components Analyses

	Controls	Hemiplegics	All
Year 1			
Eigen Value	2.43	2.19	2.25
% Variance Contribution	61	55	56
Test Loadings:			
Rhyme Detection	0.73	0.84	0.79
Rhyme Production	0.89	0.88	0.88
Phoneme Identification	0.57	0.50	0.52
Phoneme Deletion	0.88	0.67	0.75
Year 2			
Eigen Value	3.47	3.01	3.16
% Variance Contribution	69	60	63
Test Loadings:			
Rhyme Detection	0.67	0.77	0.73
Rhyme production	0.83	0.73	0.75
Phoneme Identification	0.76	0.70	0.72
Phoneme Deletion	0.90	0.83	0.85
Sound Blending	0.95	0.84	0.89
Year 3			
Eigen Value	3.35	3.51	3.48
% Variance Contribution	67	70	70
Test Loadings:			
Rhyme Detection	0.79	0.91	0.87
Rhyme Production	0.80	0.75	0.77
Phoneme Identification	0.82	0.90	0.88
Phoneme Deletion	0.83	0.82	0.82
Sound Blending	0.85	0.81	0.83

7.3.1.5 Summary of the phonological awareness analyses

The Series 1 Analyses had shown that there was, with one exception, an absence of effects of hemispheric side of insult and of seizures on phonological awareness performance, once IQ had been controlled for. The exception was with respect to rhyme production in Year 2 of the study for which significant hemispheric side of insult and interaction of hemispheric side with seizures effects were obtained. The Series 2 Analyses demonstrated that the presence of a hemispheric injury did not appear to have deleterious effects on the development of phonological awareness during the course of the two year study (over and above any effects explicable in terms of IQ variation). Finally, the Series 3 Principal Components Analyses of the phonological awareness data confirmed the presence of only one significant factor (a Global Phonological Awareness Factor) that accounted for approximately 60 - 70 percent of the variance in the phonological scores.

7.3.2 Reading, Spelling, Letter Knowledge and Arithmetic Skills

Initial data screening was conducted before proceeding with the formal analyses. Although the BAS reading test had been administered in all three years of the study, it was decided to exclude the Year 1 data because fewer than 25 percent of the children in the clinical samples obtained raw scores of greater than 0. Consequently, the only attainment test from Year 1 used in the analyses was Letter (Name) Knowledge. In Year 2 of the study, it was noted that the scores for BAS reading, Neale reading, and Schonell spelling were positively skewed. The data from these tests were subjected to appropriate logarithmic transformations before being entered into the analyses. None of the Year 3 tests suffered serious departures from normality. The two medical controls excluded from the phonological awareness analyses were also excluded from the educational attainment analyses. It has been recently reported that girls having Turner's syndrome tend to have unusually elevated reading and spelling scores (Temple, 1993).

7.3.2.1 Rationale of Analyses:

Four series of analyses were conducted of the educational attainment data:
Series 1 investigated the effects of hemispheric side of insult and of seizures on the attainments of the children in the four hemiplegic groups (the medical control group was excluded).
Series 2 and 3, which consisted of analyses of covariance with repeated measures and planned contrasts (MANOVA method, O'Brien and Kaiser, 1985), examined the development of the children's reading and spelling during the course of the study. In **Series 2**, the children from the medical control group and the two seizure-free hemiplegic groups were studied i.e. groups MC, LNS and RNS. In **Series 3**, the four hemiplegic groups were studied i.e. groups LNS, RNS, LS and RS.
Series 4 consisted of analyses of covariance with planned contrasts applied to the arithmetical attainment data of Year 3.
Year 1 WPPSI IQ was again used as a covariate in all four series of analyses.

7.3.2.2 Series 1 Analyses - The effects of hemispheric side of insult and of seizures on attainments

Data from all four groups of hemiplegic subjects (LNS, RNS, LS and RS) were entered into a series of 2-way analyses of covariance addressing the effects of hemispheric side of insult and of seizures on the attainment tests in each year of the study. The means and standard deviations of the attainment scores according to group are given in Tables 7.5 to 7.8. The large standard deviations of the literacy attainments reflect, first, the wide range of scores on this measures (i.e. marked inter-subject variability), together with the tendency for the scores to be skewed, noticeably in Year 2. As has already been pointed out, the scores for Year 2 BAS and Neale reading and for Schonell spelling were subjected to logarithmic transformations as appropriate. The analyses for each year of the study will be considered separately and in turn. Significant results for all four Series of Analyses are reported in the text and summarised in Table 7.9, while non-significant results are reported in Appendices 7.4 through 7.7.

In Year 1, the only measure analysed was that of Letter Knowledge (Table 7.5). No significant effects of hemispheric side of insult or seizures were obtained. Nor did hemipsheric side of insult interact with the effects of seizures (Appendix 7.4).

Table 7.5 - Attainment Data - Means and standard deviations of the Letter Knowledge scores in Year 1 according to Group

	Group				
	MC	**LNS**	**RNS**	**LS**	**RS**
Letter Knowledge	6.17	8.13	4.73	3.12	2.50
S.D.	8.47	8.11	4.17	4.58	1.29

S.D. - Standard deviation.
Letter Knowledge scores out of 26.

In Year 2, hemispheric side of insult had a significant effect on Letter Knowledge ($F[1,33] = 4.50$, $p < .05$). It appeared from Table 7.6 that the left hemisphere insult subjects were superior in letter naming skill compared to the right hemisphere subjects. However, Newman-Keuls tests failed to establish a significant difference between any pair of groups. The effect of seizures was not significant, nor did hemispheric side of insult interact with the effects of seizures. There were no significant effects of hemispheric side nor of seizures on BAS reading, Neale reading or Schonell spelling. However, hemispheric side of insult significantly interacted with the effects of seizures (BAS reading - $F[1,33] = 7.22$, $p < .05$; Neale reading - $F[1,33] = 8.46$, $p < .01$; Schonell Spelling - $F[1,33] = 5.30$, $p < .05$). Newman-Keuls tests revealed that Group LS performed significantly below Group LNS for both the BAS and Neale reading scores. In contrast, Group RS did not score significantly below Group RNS for either reading measure. A similar trend was evident for Schonell spelling also, but Newman-Keuls test failed to reach significance. Thus, seizures had a detrimental effect on literacy attainments in left hemisphere insult patients but not in right hemisphere insult cases.

Table 7.6 - Attainment Data - Means and standard deviations of the literacy attainment scores in Year 2 according to Group

	Group				
	MC	LNS	RNS	LS	RS
Letter Knowledge	10.11	14.20	6.09	14.75	8.75
S.D.	9.41	9.94	8.01	9.05	4.27
BAS Reading (/90)	8.06	17.20	6.09	1.12	12.00
S.D.	13.72	16.73	8.01	1.73	14.70
Neale (/151)	22.56	51.40	12.73	3.25	24.50
S.D.	40.34	55.29	16.87	3.65	27.79
Spelling (/100)	4.00	5.60	1.73	0.25	5.25
S.D.	6.62	7.20	3.58	0.71	9.21

In Year 3, there were no significant effects of side of insult or of seizures on Letter Knowledge. Nor did side of insult interact with the effects of seizures. However, the analyses of the reading and spelling tests effectively replicated the results from Year 2 (see Table 7.7). There were no significant main effects of hemispheric side of insult nor of seizures on BAS reading, Neale reading or Schonell spelling scores. However, hemispheric side of insult interacted significantly with the effects of seizures for all three measures (BAS reading - $F[1,33] = 6.37$, $p < .05$; Neale reading - $F[1,33] = 8.02$, $p < .01$; Schonell Spelling - $F[1,33] = 4.53$, $p < .05$). Newman-Keuls tests demonstrated that, for both BAS reading and Neale reading, Group LS scored significantly below Group LNS, but that there was not a difference between Groups RNS and RS. A similar trend was evident for the spelling scores but Newman-Keuls tests failed to achieve significance. Thus, seizures significantly affect literacy skills in the presence of a left hemisphere insult but not when the insult is to the right hemisphere.

Table 7.7 - Attainment Data - Means and standard deviations of the literacy attainment scores in Year 3 according to Group

	Group				
	MC	**LNS**	**RNS**	**LS**	**RS**
Letter Knowledge	17.39	18.07	16.91	15.12	16.50
S.D.	10.11	9.42	9.39	7.34	6.56
BAS Reading	26.83	31.67	16.54	5.87	23.00
S.D.	23.29	23.42	18.95	5.84	26.96
Neale Reading	84.76	130.87	49.64	23.00	79.50
S.D.	78.58	98.49	53.71	18.09	92.90
Spelling	11.56	13.53	6.45	3.62	10.00
S.D.	10.49	10.77	8.77	5.37	14.14

In Year 3 of the study, the children were given two tests of arithmetic, the WISC-R Arithmetic subtest, and a written arithmetic test (Table 7.8). There were no significant main effects of hemispheric side or of seizures on performance on either test. However, hemispheric side of insult significantly interacted with the effects of seizures (WISC-R Arithmetic - $F[1,33] = 11.80$, $p < .01$; Written arithmetic - $F[1,33] = 5.31$, $p < .05$). Newman-Keuls tests revealed that on the WISC-R Arithmetic subtest, Group LS scored significantly below Group LNS. On the written arithmetic test, Group LS scored significantly below both Groups LNS and RNS; thus, the children with left hemisphere insults scored significantly below their seizure-free counterparts. However, no differences were demonstrated between Group RS and Groups RNS or LNS. Thus, seizures affect numeracy skills when the insult is to the left hemisphere but not when it is to the right hemisphere.

Table 7.8 - Attainment Data - Means and standard deviations of the arithmetic scores in Year 3 according to Group

	Group				
	MC	LNS	RNS	LS	RS
WISC-R	11.89	11.27	9.73	6.62	9.50
S.D.	2.85	2.76	3.69	3.81	4.04
Written Arith	18.28	18.27	17.00	7.25	15.75
S.D.	8.82	7.89	9.12	6.76	12.04

WISC-R Arithmetic scaled scores (range 1 - 19)
Written Arithmetic (/27)

7.3.2.3 Series 2 Analyses - The development of reading and spelling skills in the seizure-free hemiplegic groups

The availability of longitudinal data meant that it was possible to investigate whether the clinical samples differed in their rate of literacy development. With so little reliable attainment data available for Year 1, it was decided to restrict the repeated measures analyses (MANOVA method) to Years 2 and 3 of the study. In the first series of analyses, the two seizure-free hemiplegic samples, LNS and RNS, together with the medical controls, MC, were studied. This analysis permitted an evaluation of the effects of unilateral injury and of hemispheric side of insult on literacy development, without the complicating effect of seizures. Again, significant results are quoted in the text and summarised in Table 7.9, while non-significant results are reported in Appendix 7.5.

Table 7.9 - Attainment Data - Summary of the statistically significant analyses

Series 1 Analyses: The effect of hemispheric side and of seizures on attainments

Test	Factors	F	d.f.	p
Year 2				
Letter Knowledge	Side	4.50	1,33	<.05
BAS Reading	Side x Seizure	7.22	1,33	<.05
Neale Reading	Side x Seizure	8.46	1,33	<.01
Schonell Spelling	Side x Seizure	5.30	1,33	<.05
Year 3				
BAS Reading	Side x Seizure	6.37	1,33	<.05
Neale Reading	Side x Seizure	8.02	1,33	<.01
Schonell Spelling	Side x Seizure	4.53	1,33	<.05
WISC-R Arith	Side x Seizure	11.80	1,33	<.01
Written Arith	Side x Seizure	5.31	1,33	<.01

Series 2 Analyses - The development of reading and spelling skills in the seizure-free hemiplegic groups

Test	Factors	F	d.f.	p
BAS Reading	Main Group Effect	3.35	2,40	<.05
(average scores)	LNS vs RNS	5.87	1,40	<.05
Neale Reading	Main Group Effect	6.68	2,39	<.01
(average scores)	LNS vs RNS	11.30	1,39	<.01
	LNS vs MC	8.46	1,39	<.01

Table 7.9 (cont)

Series 3 Analyses - The development of reading and spelling skills within the hemiplegic sample

Test	Factors	F	d.f.	p
BAS Reading	Main Group Effect	3.20	3,33	<.05
(average scores)	LNS vs LS	6.34	1,33	<.05
Neale Reading	Main Group Effect	5.03	3,33	<.01
(average scores)	LNS vs LS	8.58	1,33	<.01

Series 4 Analyses - Analyses of the arithmetic data

Test	Factors	F	d.f.	p
WISC-R Arith	Main Group Effect	3.66	2,40	<.05
	LNS vs RNS	7.28	1,40	<.05
WISC-R Arith	Main Group Effect	4.48	2,33	<.05
	LS vs RS	5.54	1,33	<.05
	RNS vs RS	4.67	1,33	<.05

Arith - Arithmetic.

Letter Knowledge was studied over Years 2 and 3 . No significant results were obtained in the analyses of either the average scores (Year 2 + Year 3 Letter Knowledge /2) or the change/difference scores (Year 3 minus Year 2 Letter Knowledge).

The first analysis of BAS Reading over Years 2 and 3 addressed group differences in the average scores (Year 2 + Year 3 BAS /2). There was a significant overall effect of Group ($F[2,40] = 3.35$, $p < .05$). Planned contrasts were conducted that focused on comparing Groups LNS versus RNS, the combined hemiplegic groups (LNS + RNS) versus Group MC, and Group MC versus each of Groups LNS and RNS separately. The contrasts showed that Group RNS scored significantly below Group LNS on the BAS reading tests ($F[1,40] = 5.87$, $p < .05$); the mean average BAS reading score for Group RNS was 11.32 and for Group LNS, 24.43. The analyses of change scores (Year 3 minus Year 2 BAS) showed the groups did not differ in their rate of improvement on the BAS reading test.

For the Neale Reading average scores (Year 2 + Year 3 Neale /2), there was a significant effect of Group ($F[2,39] = 6.68$ $p < .01$). Planned contrasts showed that, first, Group RNS was inferior to Group LNS ($F[1,39] = 11.30$, $p < .01$); the mean average score for Group RNS was 31.18, and for Group LNS, 91.13. Second, Group MC read fewer Neale words correctly than did Group LNS ($F[1,39] = 8.46$, $p < .01$); the mean average score for Group MC was 61.76. The analyses of the change scores (Year 3 minus Year 2 Neale) produced no significant results, indicating that the groups did not differ in their rate of improvement in Neale reading over Years 2 and 3.

For the Schonell Spelling data, neither the analyses of the average scores (Year 2 + Year 3 Spelling /2) nor the change scores (Year 3 minus Year 2 Spelling) produced significant results.

7.3.2.4 Series 3 Analyses - The development of reading and spelling skills within the hemiplegic samples

Analyses of covariance with repeated measures analyses were then conducted for all four hemiplegic groups, including the seizure samples, but excluding the medical control group i.e. LNS, RNS, LS and RS. These analyses permitted the study of group differences and of rate of improvement i.e. with increasing age, taking account of both hemispheric side of insult and seizure effects. Once again, significant results are summarised in Table 7.9 and non-significant results reported in Appendix 7.6.

For Letter Knowledge average and change score data, no significant effects were obtained.

The BAS Reading average score data showed a significant effect of Group ($F[3,33] = 3.20$, $p < .05$). Planned contrasts focused on comparing Groups LS versus RS, the combined non-seizure versus combined seizure groups (LNS + RNS versus LS + RS), Groups LNS versus LS, and Groups RNS versus RS. Groups LNS and RNS comparisons had been covered in the Series 2 Analyses planned contrasts. The contrasts revealed that Group LS scored significantly below Group LNS on BAS reading ($F[1,33] = 6.34$, $p < .05$); the mean average score for the Group LNS was 24.43 and for Group LS only 3.50. The BAS change scores showed no significant effects.

The analyses of the Neale Reading data produced results similar to those of the BAS. The average score analyses showed a significant effect of Group ($F[3,33] = 5.03$, $p < .01$). Planned contrasts demonstrated that Groups LS scored significantly below Group LNS on Neale reading ($F[1,33] = 8.58$, $p < .01$); the mean average Neale score for Group LNS was 91.13, while for Group LS the mean score was only 13.12. No significant results were obtained from the analyses of the Neale change scores.

The Schonell Spelling data were subjected to repeated measures analyses for both average and change scores, but no significant results were obtained.

7.3.2.5 Series 4 Analyses - Analyses of the Arithmetic data

The Year 3 data pertaining to WISC-R Arithmetic and written arithmetic were entered into a series of analyses of covariance (c.f. Series 2 and 3 Analyses of the literacy data).

First, the WISC-R Arithmetic and written arithmetic scores of Groups LNS, RNS and MC were analysed. There was a significant effect of Group for WISC-R Arithmetic ($F[2,40] = 3.66$, $p < .05$). Planned contrasts showed that Group RNS scored significantly below Group LNS ($F[1,40] = 7.28$, $p < .05$). No significant results were obtained when the written arithmetic data were analysed (Appendix 7.7).

The second series of analyses examined the WISC-R Arithmetic and written arithmetic scores within the hemiplegic sample, including the seizure groups. There was a significant effect of Group for the WISC-R Arithmetic data ($F[2,33] = 4.48$, $p < .05$). Planned contrasts showed that Groups LS scored significantly below both Group RS ($F[1,33] = 5.54$, $p < .05$) and Group LNS in WISC-R Arithmetic ($F[1,33] = 6.63$, $p < .05$). Inspection of Table 7.8 suggested that Group LS was particularly disadvantaged relative to the other groups. Group RS also scored below Group RNS ($F[1,33] = 4.67$, $p < .05$), a surprising result in view of the small apparent difference between their mean scores. The results from the written arithmetic test failed to achieve significant levels.

7.3.2.6 Summary of the attainments analyses

The Series 1 Analyses showed that for BAS and Neale reading, Schonell spelling, and oral and written Arithmetic there were no significant main effects of hemispheric side of insult or of seizures. However, hemispheric side of insult consistently interacted with the effects of seizures. Post hoc tests and the results of the Series 3 and 4 Analyses revealed that this interaction was explained by the fact that seizures had a deleterious effect on reading and oral Arithmetic when the hemispheric insult was to the left side but not when the insult was to the right side (the results for spelling and written arithmetic fell short of significance); this effect did not arise from differences in IQ as this was entered as a covariate in all the analyses. The Series 2 Analyses showed that, while the seizure-free hemiplegic groups did not differ significantly from the medical controls in their attainments, there was a tendency for the left hemispheric insult group to be performing at a higher level than the right insult group.

7.4 Discussion

7.4.1 Phonological Awareness:

The Series 1 Analyses showed that there was, in general, an absence of effects of hemispheric side of insult and of seizures on phonological awareness, once IQ had been controlled for. The exception was in respect of rhyme production in Year 2 which showed a significant effect of hemispheric side of insult and a significant interaction of hemispheric side with seizures. In the non-seizure sample, the right hemisphere insult group achieved a significantly lower mean rhyme production score than did the left hemisphere group. For the seizure sample, the reverse trend was evident; the left seizure group had a lower rhyme production score than did the right seizure group, though on post hoc testing these differences failed to reach significance. It may be that these results constitute an artifactual finding since they occurred in isolation. No other phonological awareness measures showed this effect, nor was this result demonstrable in Years 1 and 3 in which rhyme production data were also available. It is also worth noting that this pattern was not observable for IQ or any of the language measures studied (Chapters 5 and 6).

The Series 2 Analyses showed that the presence of an early unilateral cerebral injury did not appear to have a specifically deleterious effect on phonological awareness performance during the two years of the study, over and above any effects explicable in terms of IQ variation; when the hemiplegic groups' scores were compared with those of the medical control group, no significant differences emerged, after controlling for IQ.

These findings extend the recent work supporting the relative equipotentiality of the early-injured brain beyond the domain of selective aspects of language to the hitherto unexplored domain of phonological awareness, a metalinguistic skill of a high level and one which has an important bearing on children's early reading development. On the face of it, the present findings appear to contradict the results of the study by Patterson, Vargha-Khadem and Polkey (1988) who found that left hemidecortication severely impaired phonological processing. However, in their subject, the injury to the left hemisphere was acquired through late onset epilepsy so that the potential for functional reorganisation may have been very restricted. The findings of the present study suggest that when the injury is incurred early, the remaining intact regions of the brain are able to assume phonological processing capacities which in older individuals might well be fixed within specific regions of the left hemisphere.

The Principal Components Analyses conducted in the Series 3 Analyses failed to replicate the normal group finding of two relatively independent subskills (rhyming and segmentation) underlying phonological ability. For all the clinical groups, only one significant factor of Global Phonological Awareness emerged in each of the three years of the study, accounting for approximately 60 - 70 percent of the variance, and on which the individual tests loaded moderately highly (ranging from 0.5 up to 0.9). The failure to uncover two factors might be explained in either of two ways. First, it may be that the two factors did exist within the clinical phonological awareness data, but they proved difficult to detect because of the relatively small and more heterogeneous nature of the clinical sample. Alternatively, one might speculate that phonological awareness skills in clinical populations are less refined and not as clearly differentiated as they are in normal populations. This might be expected to affect the relationship between phonological awareness and literacy attainments, an issue that is addressed in the following chapter.

7.4.2 Reading, Spelling and Arithmetic Attainments:

The interpretation of the attainments analyses for the seizure-free hemiplegics and the medical controls will be considered first (Series 2 Analyses). The right hemisphere insult group scored significantly below the left hemisphere insult group in reading (both BAS and Neale) and in oral Arithmetic in Years 2 and 3 of the study. Indeed, the left hemisphere group proved remarkably competent in reading and on one measure even surpassed the medical controls i.e. on Neale reading. However, the right hemisphere group did not fall below the level of the medical controls on any of the reading scores. Thus, one might conclude that a unilateral cerebral insult incurred pre- or peri-natally, and which is without seizure complication, has little or no effect on early literacy development. This is true even when that insult is to the language-sensitive left hemisphere. These findings suggest that the left hemisphere is capable of sufficiently comprehensive and sophisticated reorganisation to support the development of phonological and literacy skills. The results are broadly in keeping with those of Aram and Ekelman (1988) who found no marked decrements in educational performance in their hemiplegic sample, irrespective of side of injury. It is interesting to speculate why the left hemisphere insult subjects in this study had rather inflated reading and arithmetic scores. This proved to be a robust finding, evident on more than one measure and across several analyses. In the absence of a theoretically parsimonious explanation, it is suggested that the differences may be accounted for by environmental factors, such as parental input and schooling experiences, which were not systematically assessed or controlled in this study, and to which educational attainments, above other cognitive skills, are particularly susceptible.

The left hemisphere seizure group performed poorly relative to the seizure-free left hemisphere group on the BAS and Neale reading tests in Years 2 and 3. This group was also substantially impaired in mental arithmetic relative to both its non-seizure counterpart and even relative to the right seizure group. Thus, the left hemisphere seizure patients appeared to be experiencing particular difficulty educationally. Their difficulties were not explicable in terms of the lower IQ of the seizure groups since IQ was used as a covariate in all the analyses.

In general, one might conclude that the presence of an early unilateral insult, without seizure complication, produces no marked effects on literacy or numeracy skills. It is proposed that even in left hemisphere insult cases, functional reorganisation is sufficient to support at least the early stages of educational development. However, when seizure episodes occur in children with a left hemisphere insult, there are detrimental effects on educational development, an observation that cannot be solely accounted for by the lower IQ of the seizure cases. In keeping with the argument developed in Chapter 6, one might speculate that seizures (and possibly medication) interfere with the capacity of the remaining intact brain regions in left hemisphere insult cases to undergo the necessary, and usually successful, functional reorganisation that would permit educational skills to develop.

To be fair, this argument is weakened somewhat by the fact that on the BAS and Neale reading measures, the left hemisphere children with seizures performed poorly relative only to the strikingly competent seizure-free left hemisphere children. However, the left hemisphere with seizures patients performed poorly on mental arithmetic relative to both the seizure-free left hemisphere patients and the right hemisphere children with seizures.

Inspection of the means across a wide range of measures showed that the left hemisphere with seizures children were the lowest performing of all the groups; this was especially true of the language tests (Tables 6.4 to 6.6) and the attainment measures (Tables 7.5 to 7.8), and to a lesser degree, the phonological awareness tests also (Tables 7.1 to 7.3). Thus, the hypothesis of selective interference of seizures with left hemisphere function is worthy of further investigation in a larger group of subjects.

7.5 Conclusion

The presence of a unilateral lesion (irrespective of side) appeared to have no significant detrimental effects on phonological awareness development during the two years during which this study was conducted, other than those that might be accounted for by IQ variation. Such a lesion, provided that it was not accompanied by seizures, also failed to result in impairment of educational functioning. Indeed, the seizure-free left-hemisphere-injured children were performing remarkably well in terms of their literacy and arithmetical attainments, and neither the left nor right seizure-free groups were impaired relative to the medical controls on any of the educational measures. However, the left-hemisphere-injured group who also had seizures was particularly disadvantaged in reading and arithmetical attainments relative to the seizure-free left-hemisphere-injured group (and in arithmetic, relative also to the right hemisphere seizure group) - an observation not solely explicable in term of the lower IQ of the seizure groups. It is proposed that the presence of seizures in the left hemisphere group interferes with the functional reorganisation required to sustain educational progress, a process which is able to proceed unhindered in the non-seizure left hemisphere children.

Chapter 8

Phonological Awareness and its Relationship to Literacy Attainments in Hemiplegic Children

8.1 Introduction

The analyses of the phonological awareness, reading and spelling data showed that children with a hemispheric insult, who were free of seizure complication, were able to develop competent phonological and early literacy skills. However, additional questions might be posed that explore the nature of the relationship between phonology and literacy within a neuropsychological framework; this chapter attempts to answer some of these questions. Chapter 8 took as its point of departure the model of early literacy development that had been formulated using 38 normal children, and which was described in Chapter 2. The model was based on a longitudinal study that examined the relationship between phonological awareness, letter name knowledge, memory skills and literacy progress in normal children during their first two years at school.

In the model of normal literacy development, phonological segmentation ability (but not rhyming) had a significant effect on progress in reading and spelling during the first year at school; letter knowledge, and its interaction with segmentation, also contributed to first year reading and spelling. In the following year, segmentation skills, now in conjunction with rhyming ability, exerted an influence over spelling (though not reading). An important question to answer is whether this evident phonology-literacy connection can be replicated in a brain-injured sample. If it can, then this argues for the strength and meaningfulness of this relationship (Patterson and Vargha-Khadem, 1991). Consequently, the relationship between phonology and literacy (and between letter knowledge and literacy) was studied within the hemiplegic sample.

A second question that might be posed is whether the phonology-literacy connection can be disrupted by specific brain injuries. The defining characteristics of the hemiplegic sample made it possible to explore laterality differences in the strength of this connection i.e. is a left hemisphere injury more likely to disrupt the link between phonology and literacy than a right hemisphere injury? Moreover, if the phonology-literacy connection can be disrupted under specified neurological conditions, it may provide information about processes of functional organisation and prioritisation within the early-injured, still developing, brain.

Finally, are children in whom the reading-phonology connection is disrupted still able to learn to read? If so, what role do other cognitive skills have in enabling the compensation for the loss of a connection that is crucial to literacy development in normal children? Possible candidates for alternative contributory skills are auditory/verbal and visual memory skills. Memory did not play a substantial role in the development of reading and spelling within the normal sample, but that is not to say that the importance of memory skills might not be upgraded in the absence of a firm phonology-literacy connection. Consequently, it was necessary to investigate the links between literacy and memory in the hemiplegic children.

Phonological awareness, letter knowledge and memory skills and their relationships with reading and spelling were studied in only the seizure-free hemiplegic and medical control groups. The seizure groups were excluded partly because of small sample size, but also because the correlational analyses conducted did not permit the partialling out of the effect of IQ. Since the Principal Components analyses conducted on the clinical groups' phonological awareness data had failed to uncover the two separate factors established for the normal controls (Chapter 7), it was necessary to analyse the results from the individual phonological awareness tests.

8.2 Method

The subjects, materials, design and methodology are fully described in Chapters 2 and 5.

8.3 Results

8.3.1 Rationale of Analyses:

The small and variable group sizes limited the scope of the "relationship" analyses; patterns of correlations were studied, and the significance of the between groups differences in correlations analysed using Fisher's z transformation statistic (Ferguson, 1981). It was decided to concentrate on four subject groups: the normal controls (NC) with whom the model of literacy development described in Chapter 2 had been developed, the medical controls (MC), and the two larger hemiplegic groups i.e. the left and right hemisphere non-seizure groups (LNS and RNS). The two medical control subjects excluded from the analyses in Chapter 7 were also excluded from the analyses described in this chapter. Thus, 38 normal controls, 18 medical controls, 15 left-hemisphere-injured patients and 11 right-hemisphere-injured patients were studied.

Series of correlation matrices were produced. The following Year 1 measures were correlated with Year 2 BAS reading, Neale reading and Schonell spelling: Full Scale WPPSI IQ, rhyme detection, rhyme production, phoneme identification, phoneme deletion, letter (name) knowledge, digit span and the Goulandris visual memory test. WPPSI IQ was also correlated with the Year 3 reading and spelling measures.

The Year 2 phonological awareness tests (that now also included ITPA sound blending), letter knowledge, digit span and the Goulandris test were correlated with BAS reading, Neale reading and Schonell spelling from both Years 2 and 3.

Finally, all the Year 3 phonological awareness, letter knowledge and memory tests were correlated with Year 3 BAS reading, Neale reading and Schonell spelling.

Logarithmically transformed data were used in the analyses as appropriate.

Three series of correlational analyses were conducted:

Series 1 compared the patterns of correlations of phonological awareness, letter knowledge and literacy attainments in the normal and medical control groups in order to determine whether the performance of the medical control group resembled that of the original sample of normal children.

Series 2 compared the patterns of correlations of phonological awareness, letter knowledge and literacy attainments in the left- and right-hemisphere-injured groups and the medical control group in order to determine whether hemispheric injury and side of insult affected the nature and extent of the relationship between these skills.

Series 3 compared the patterns of correlations of verbal memory, visual memory and literacy attainments in the left- and right-hemisphere-injured groups and the two control groups in order to determine whether the relationships between these skills are influenced by the presence of a hemispheric injury and its side of insult.

The correlation matrices, and the significance of the correlations, are summarised in Tables 8.1 through 8.14. Significant Fisher's z transformation statistics are quoted in the text. Significant and non-significant Fisher's z transformation statistics are given in full in Appendices 8.1 and 8.2.

8.3.2 Series 1 Analyses - Correlational patterns of phonological awareness, letter knowledge and literacy attainments in the normal and medical control groups

To see if the relationship between phonological awareness, letter knowledge and literacy attainment in the medical control group was representative of that observed for the original sample of normal children, the patterns of correlations (and their statistical significance) were compared in the normal and medical control groups. The correlation matrices are given in Tables 8.1 through 8.5. The similarities between the correlation matrices for the two control groups were quite striking, particularly when the correlations for Years 2 and 3 were studied.

IQ correlated moderately highly with Years 2 and 3 reading and spelling performance for both groups (Table 8.1).

Table 8.1 - Phonological Awareness and Literacy Attainments - Correlations of IQ with Years 2 and 3 literacy attainments (Normal Controls, NC, and medical controls, MC)

	Group	**BAS**	**Neale**	**Spelling**
			Year 2	
IQ	NC	0.40**	0.29*	0.38**
	MC	0.51*	0.33	0.54*
			Year 3	
IQ	NC	0.42**	0.42**	0.38**
	MC	0.64**	0.70**	0.43*

The Year 1 measures' correlations with the literacy attainments in Year 2 showed some disparity between the groups, and a far from clear and consistent pattern even within groups (Table 8.2).

Table 8.2 - Phonological Awareness and Literacy Attainments - Correlations of Year 1 phonological awareness and letter knowledge with Year 2 literacy attainments (NC and MC)

			Year 2	
	Group	**BAS**	**Neale**	**Spelling**
Year 1				
Rhyme Detection	NC	0.25*	0.22	0.22
	MC	0.44*	0.31	0.37
Rhyme Production	NC	0.15	0.09	0.20
	MC	0.65**	0.66**	0.60**
Ph Identification	NC	0.26	0.28*	0.51**
	MC	0.70**	0.54*	0.49*
Ph Deletion	NC	0.06	0.06	0.33*
	MC	0.60**	0.60**	0.33
Letter Knowledge	NC	0.48**	0.45**	0.26
	MC	0.33	0.33	0.14

Ph - Phoneme.

The correlations of Year 2 phonological awareness with Years 2 and 3 literacy attainments showed a consistent pattern within the two control groups, and a distinct similarity between them (Tables 8.3 and 8.4). In accord with the findings of Chapter 2, the segmentation tests (phoneme identification, phoneme deletion and sound blending) showed consistently high, and indeed statistically significant, correlations with the literacy measures; this was in contrast to the rhyming measures which had lower correlations with the reading and spelling tests. Year 2 letter knowledge correlated highly with the literacy measures in Years 2 and 3 for both control groups (Tables 8.3 and 8.4).

Table 8.3 - Phonological Awareness and Literacy Attainments - Correlations of Year 2 phonological awareness and letter knowledge with year 2 literacy attainments (NC and MC)

			Year 2	
	Group	**BAS**	**Neale**	**Spelling**
Year 2				
Rhyme Detection	NC	0.25	0.22	0.22
	MC	0.33	0.20	0.19
Rhyme Production	NC	0.02	0.04	0.20
	MC	0.38	0.25	0.39
Ph Identification	NC	0.42**	0.44**	0.46**
	MC	0.60**	0.38	0.52*
Ph Deletion	NC	0.48**	0.47**	0.52***
	MC	0.83***	0.61**	0.77***
Sound Blending	NC	0.38**	0.31*	0.65***
	MC	0.69**	0.46*	0.78***
Letter Knowledge	NC	0.71***	0.73**	0.46**
	MC	0.75***	0.58**	0.52*

Table 8.4 - Phonological Awareness and Literacy Attainments - Correlations of Year 2 phonological awareness and letter knowledge measures with Year 3 literacy attainments (NC and MC)

			Year 3	
	Group	**BAS**	**Neale**	**Spelling**
Year 2				
Rhyme Detection	NC	-0.03	0.00	0.13
	MC	0.56**	0.54*	0.42*
Rhyme Production	NC	0.15	0.07	0.36*
	MC	0.35	0.37	0.24
Ph Identification	NC	0.44**	0.45**	0.43**
	MC	0.66**	0.61**	0.65**
Ph Deletion	NC	0.55***	0.60***	0.70***
	MC	0.77***	0.80***	0.72***
Sound Blending	NC	0.48**	0.49**	0.49**
	MC	0.65**	0.68**	0.65**
Letter Knowledge	NC	0.69***	0.68***	0.55***
	MC	0.83***	0.82***	0.73***

Year 3 rhyming, segmentation and letter knowledge all showed consistently high correlations with the concurrent literacy measures for both control groups (Table 8.5).

Table 8.5 - Phonological Awareness and Literacy Attainments - Correlations of Year 3 phonological awareness and letter knowledge with Year 3 literacy attainments (NC and MC)

	Group	BAS	Year 3 Neale	Spelling
Year 3				
Rhyme Detection	NC	0.41**	0.39**	0.37*
	MC	0.57**	0.57**	0.37
Rhyme Production	NC	0.47**	0.50**	0.48**
	MC	0.61**	0.67**	0.36
Ph Identification	NC	0.37*	0.35*	0.52***
	MC	0.51*	0.52*	0.51*
Ph Deletion	NC	0.52***	0.53***	0.67***
	MC	0.74***	0.66**	0.74***
Sound Blending	NC	0.56***	0.55***	0.75***
	MC	0.74***	0.69**	0.77***
Letter Knowledge	NC	0.62***	0.59***	0.43**
	MC	0.78***	0.74***	0.74***

It was concluded that the patterns of correlations between phonological awareness/letter knowledge and literacy attainment in the medical control group closely resembled those of the normal control group, at any rate for Years 2 and 3. The medical control group was thus considered to be representatively normal. For this reason, and to achieve procedural parity with the analyses conducted in Chapters 5 - 7, it was decided to compare the hemiplegic groups with the medical (as opposed to the normal) control

Footnote*: It should be noted that some variations from the pattern of performance of the normal control group were observed in the medical control group that are worthy of further investigation.

group, in the subsequent between groups comparisons of the correlations.

8.3.3 Series 2 Analyses - Correlational patterns of phonological awareness, letter knowledge and literacy attainments in the hemiplegic and medical control groups

Tables 8.6 through 8.10 summarise the correlation matrices for the left- and right-hemispheric-injured groups. The correlations of IQ with Years 2 and 3 literacy attainment in Groups LNS and RNS were modest and only rarely achieved statistical significance (Table 8.6).

Table 8.6 - Phonological Awareness and Literacy Attainments - Correlations of IQ with Years 2 and 3 literacy attainments (Left and right hemisphere insult groups, LNS and RNS)

	Group	BAS	Neale	Spelling
			Year 2	
IQ	LNS	0.17	0.23	0.45*
	RNS	0.38	0.59*	0.27
			Year 3	
IQ	LNS	0.27	0.28	0.26
	RNS	0.42	0.53*	0.50

Inspection of Tables 8.7 through 8.10 revealed a trend towards "double dissociation". The Years 2 and 3 phonological awareness measures (particularly phoneme deletion and sound blending) correlated highly with the BAS and Neale reading measures for Group RNS. In contrast, the correlations of phonological awareness with reading were substantially lower for Group LNS. The reverse pattern appeared to be the case when looking at the relationship between letter knowledge and reading. The correlations of these measures were generally much higher in Group LNS than Group RNS. The double dissociation trend was evident for spelling also, but the pattern was less clear and consistent than for reading.

Table 8.7 - Phonological Awareness and Literacy Attainments - Correlations of Year 1 phonological awareness and letter knowledge with Year 2 literacy attainments (LNS and RNS)

			Year 2	
	Group	**BAS**	**Neale**	**Spelling**
Year 1				
Rhyme Detection	LNS	0.60**	0.65*	0.81***
	RNS	0.70**	0.82**	0.51
Rhyme Production	LNS	0.36	0.42	0.73**
	RNS	0.54*	0.61*	0.56*
Ph Identification	LNS	0.45*	0.54*	0.64**
	RNS	0.52*	0.42	0.42
Ph Deletion	LNS	0.45*	0.47*	0.57*
	RNS	0.48	0.47	0.13
Letter Knowledge	LNS	0.74**	0.71**	0.67**
	RNS	0.44	0.65*	0.31

Table 8.8 - Phonological Awareness and Literacy Attainments - Correlations of Year 2 phonological awareness and letter knowledge with Year 2 literacy attainments (LNS and RNS)

			Year 2	
	Group	**BAS**	**Neale**	**Spelling**
Year 2				
Rhyme Detection	LNS	0.43	0.46*	0.51*
	RNS	0.44	0.53*	0.47
Rhyme Production	LNS	0.33	0.36	0.43
	RNS	0.02	0.19	-0.01
Ph Identification	LNS	0.56*	0.59*	0.77***
	RNS	0.76**	0.78**	0.58*
Ph Deletion	LNS	0.46*	0.50*	0.71**
	RNS	0.75**	0.76**	0.76**
Sound Blending	LNS	0.22	0.26	0.53
	RNS	0.85**	0.80**	0.77**
Letter Knowledge	LNS	0.83***	0.76**	0.56
	RNS	0.50	0.76**	0.45

Table 8.9 - Phonological Awareness and Literacy Attainments - Correlations of Year 2 phonological awareness and letter knowledge with Year 3 literacy attainments (LNS and RNS)

			Year 3	
	Group	**BAS**	**Neale**	**Spelling**
Year 2				
Rhyme Detection	LNS	0.24	0.24	0.33
	RNS	0.65*	0.62*	0.51
Rhyme Production	LNS	0.35	0.08	0.37
	RNS	0.02	0.11	-0.02
Ph Identification	LNS	0.47*	0.37	0.62**
	RNS	0.62*	0.68*	0.69*
Ph Deletion	LNS	0.44*	0.21	0.60**
	RNS	0.84**	0.87***	0.70**
Sound Blending	LNS	0.21	-0.07	0.32
	RNS	0.69**	0.69**	0.64*
Letter Knowledge	LNS	0.77**	0.61**	0.72**
	RNS	0.43	0.51	0.51

Table 8.10 - Phonological Awareness and Literacy Attainments - Correlations of Year 3 phonological awareness and letter knowledge with Year 3 literacy attainments (LNS and RNS)

			Year 3	
	Group	**BAS**	**Neale**	**Spelling**
Year 3				
Rhyme Detection	LNS	0.27	0.23	0.39
	RNS	0.54*	0.62*	0.64*
Rhyme Production	LNS	0.20	-0.01	0.26
	RNS	0.26	0.39	0.44
Ph Identification	LNS	0.43	0.14	0.53*
	RNS	0.51	0.63*	0.61*
Ph Deletion	LNS	0.41	0.15	0.62**
	RNS	0.82**	0.88***	0.89***
Sound Blending	LNS	0.31	0.08	0.52*
	RNS	0.82**	0.80**	0.81**
Letter Knowledge	LNS	0.77***	0.34	0.71**
	RNS	0.51	0.48	0.55*

The following measures were selected for between groups analyses using the Fisher z transformation statistic: phoneme deletion, sound blending and letter knowledge from Years 2 and 3 and their correlations with Years 2 and 3 BAS reading, Neale reading and Schonell spelling. For ease of interpretability, the Year 1 phonological awareness and letter knowledge correlations (with Year 2 attainments), which had tended to show less clear and consistent patterns, were excluded. Three sets of between groups analyses were conducted, specifically comparing Group LNS versus Group RNS, Group LNS versus Group MC, and Group RNS versus Group MC. The results of these Fisher's z analyses (significant and non-significant) are reported in full in Appendix 8.1.

Group LNS versus Group RNS

When the correlations for Group LNS were compared with those of Group RNS, the following statistically significant differences were obtained:
Correlation of Year 2 phoneme deletion with Year 3 BAS reading ($z = 2.48$, $p < .05$);
Correlation of Year 3 phoneme deletion with Year 3 Neale reading ($z = 2.73$, $p < .01$);
Correlation of Year 2 sound blending with Year 2 BAS reading ($z = 2.30$, $p < .05$);
Correlation of Year 2 sound blending with Year 3 Neale reading ($z = 1.98$, $p < .05$);
Correlation of Year 3 sound blending with Year 3 Neale reading ($z = 2.27$, $p < .05$).
In each of the above comparisons (and for the non-significant results, also), the correlations for Group LNS were lower than for Group RNS.

None of the analyses of differences between correlations of letter knowledge with literacy attainment achieved statistical significance.

Group LNS versus Group MC

The differences between correlations were then studied for Groups LNS and MC. The following statistically significant results were obtained:
Correlation of Year 2 phoneme deletion with Year 3 Neale reading ($z = 2.35$, $p < .05$);
Correlation of Year 2 sound blending with Year 3 Neale reading ($z = 2.13$, $p < .05$);
Correlation of Year 3 sound blending with Year 3 Neale reading ($z = 1.97$, $p < .05$).
In each of the above comparisons (and this holds true for the non-significant analyses also), Group LNS showed lower correlations than Group MC.

The analyses comparing the correlation of letter knowledge with literacy attainments in Groups MC and LNS did not attain statistical significance.

Group RNS versus Group MC

Finally, when the correlations of phonological awareness/letter knowledge with literacy attainments were compared for Groups RNS versus MC, no statistically significant differences were obtained.

8.3.4 Series 3 - Analyses - Correlational patterns of the verbal memory, visual memory and literacy attainments in the hemiplegic and control groups

The relationships between verbal or visual memory skills and literacy development were studied in a series of correlation matrices. Years 1 and 2 digit span and visual memory test scores were correlated with Year 2 reading and spelling measures, and Years 2 and 3 digit span and visual memory scores were correlated with Year 3 reading and spelling measures. The correlation matrices for Groups NC, MC, LNS and RNS are summarised in Tables 8.11 through 8.14.

Inspection of Tables 8.11 and 8.12 showed that, in general, the correlations of **verbal memory** with literacy attainments were relatively high and statistically significant in the two hemiplegic groups. Indeed, they were somewhat higher than in the medical control and normal control groups; Groups NC and MC showed similar and modest correlations of verbal memory with attainments. Analyses using the Fisher z transformation statistic of the between groups differences in correlations were conducted for Groups MC, LNS and RNS (these statistics are reported in full in Appendix 8.2). First, there were no significant differences between Groups LNS and RNS in relation to their verbal memory-attainment correlations. When the correlations of Group LNS were compared with those of Group MC, the correlation of Year 2 Verbal Memory with Year 2 Neale reading was lower in Group MC than Group LNS ($z = 2.00$, $p < .05$). Similarly, when the correlations of Group RNS were compared with those of Group MC, the correlation of Year 2 Verbal Memory with Year 2 Neale Reading was significantly lower in Group MC than Group RNS ($z = 2.48$, $p < .05$).

Table 8.11 - Verbal Memory and Literacy Attainments - Correlations of Years 1 - 3 Digit Span scores with Years 2 and 3 literacy attainments (Groups NC and MC)

Digit Span	Group	BAS	Neale	Spelling
			Year 2	
Year 1	NC	0.49***	0.47**	0.38**
	MC	0.25	0.01	0.13
Year 2	NC	0.37*	0.34*	0.34*
	MC	0.32	0.07	0.36
			Year 3	
Year 2	NC	0.37*	0.34*	0.40**
	MC	0.49*	0.38	0.39
Year 3	NC	0.21	0.17	0.23
	MC	0.48*	0.55*	0.52*

Table 8.12 - Verbal Memory and Literacy Attainments - Correlations of Years 1 - 3 Digit Span scores with Years 2 and 3 literacy attainments (Groups LNS and RNS)

Digit Span	Group	BAS	Neale	Spelling
			Year 2	
Year 1	LNS	0.72**	0.76**	0.65*
	RNS	0.58*	0.74**	0.63*
Year 2	LNS	0.63**	0.69**	0.69**
	RNS	0.66*	0.82**	0.77**
			Year 3	
Year 2	LNS	0.61**	0.38	0.61**
	RNS	0.73**	0.75**	0.77**
Year 3	LNS	0.68**	0.38	0.72**
	RNS	0.51	0.63*	0.63*

The pattern of correlations for **visual memory** with literacy attainment was less clear and consistent (Tables 8.13 and 8.14). The visual memory-attainment correlations for Groups NC and MC were quite similar and, as with verbal memory, comparatively modest. There was a suggestion that the visual memory-attainment correlations were higher in Group LNS than RNS but the (Fisher's z) differences never achieved statistical significance (Appendix 8.2). Group RNS appeared to have lower visual memory-attainment correlations than Group MC, but only one comparison showed a statistically significant difference; the Year 2 Visual Memory correlation with concurrent Neale reading was significantly lower in Group RNS than Group MC ($z = 2.43$, $p < .05$).

Table 8.13 - Visual Memory and Literacy Attainments - Correlations of Year 1 - 3 Visual Memory scores with Years 2 and 3 literacy attainments (Groups NC and MC)

Visual Memory	Group	BAS	Neale	Spelling
			Year 2	
Year 1	NC	0.23	0.26	0.19
	MC	0.35	0.24	0.35
Year 2	NC	0.37*	0.36*	0.49**
	MC	0.62**	0.69**	0.45*
			Year 3	
Year 2	NC	0.36*	0.32*	0.36*
	MC	0.34	0.37	0.32
Year 3	NC	0.06	0.03	0.13
	MC	0.33	0.41	0.24

Table 8.14 - Visual Memory and Literacy Attainments - Correlations of Years 1 - 3 Visual Memory scores with Years 2 and 3 literacy attainments (Groups LNS and RNS)

Visual Memory	Group	BAS	Neale	Spelling
			Year 2	
Year 1	LNS	0.51*	0.51*	0.21
	RNS	0.03	0.03	-0.03
Year 2	LNS	0.13	0.20	0.30
	RNS	-0.09	-0.22	-0.11
			Year 3	
Year 2	LNS	0.16	0.15	0.30
	RNS	-0.04	-0.05	0.06
Year 3	LNS	0.47*	0.51*	0.63**
	RNS	0.13	0.20	0.33

8.3.5 Summary of Results

Inspection of Tables 8.1 through 8.5 and the Series 1 Analyses confirmed that the phonological awareness and literacy correlation matrices of the normal and medical control groups were strikingly similar. However, Tables 8.6 through 8.10 and the Series 2 Analyses showed that the comparable correlation matrices of the left and right hemispheric insult groups showed certain qualitative differences. The right hemisphere insult group's pattern resembled that of the controls in that the phonological awareness measures (particularly phoneme deletion and sound blending) correlated highly with reading. In contrast, the children with left hemisphere insults showed lower correlations of the phonological awareness measures with reading. There was a tendency for the left hemisphere insult group to have higher correlations of letter knowledge with reading than the right hemisphere group. Inspection of Tables 8.11 and 8.12 and the results of the Series 3 Analyses suggested that the hemiplegic samples showed higher correlations of verbal memory with reading compared with the medical control group. Finally, the right hemisphere insult group tended to show lower correlations of visual memory with reading performance compared with either the medical control or left hemisphere insult groups (Tables 8.13 and 8.14, and Series 3 Analyses).

8.4 Discussion

The Series 1 Analyses in this study established that the strong relationship between phonological awareness and literacy attainment initially established in the normal control group could be replicated in an alternative group of non-neurologically impaired children. This suggests that the phonology-literacy connection measured by these particular tests is a robust finding. However, the analyses of the left- and right-hemispheric-insult groups showed certain qualitative differences, that were confirmed in a number of between groups analyses of the correlation coefficients.

In general, the results suggested a trend towards double dissociation. The right hemisphere insult group showed statistically significant correlations of the phonological awareness measures (particularly phoneme deletion and sound blending) with the BAS and Neale reading measures. This was a pattern evident in the normal and medical control groups also. Indeed, no significant differences emerged when between group comparisons of the correlations of the right hemisphere insult group and the medical control group were made. This suggests that children having a right hemisphere insult use phonological awareness skills to promote reading and spelling development in a manner similar to that observed in normal children. In contrast, the children with left hemisphere insults showed lower, and frequently non-significant, correlations of the phonological awareness measures with reading. When the correlations of the left insult group were compared with those of the right insult or medical control groups, several of the observed differences achieved statistical significance. On a cautionary note, given the small group sizes and the relatively large number of statistical analyses, these findings should be treated as preliminary, and the ensuing discussion regarded as speculative. It is proposed that, while children with left hemisphere insults appear to acquire phonological awareness and early reading and spelling skills without difficulty, they may not use phonological processes for promoting literacy development in the same way as either normal or right insult cases. It could be that the left hemisphere is uniquely specialised, not so much for the development of literacy and phonological skills per se, but for their interaction and integration. Thus, the capacity of other regions of the brain to take over these integrative functions, even in the case of very early injury, may be limited.

It was noted that the left hemisphere insult group achieved higher correlations of letter knowledge with literacy than the right hemisphere insult group. However, the differences did not achieve statistical significance. One could speculate that had the group sizes been even a little larger, some statistically significant differences may have been obtained. It is tempting to hypothesise that children with left hemisphere insults make use of other reading related skills, such as their letter knowledge, to promote their literacy development in the absence of phonological abilities. The apparent double dissociation trend awaits replication with larger groups but is clearly worthy of further exploration.

In order to determine whether alternative skills, such as verbal or visual memory, might play an enhanced role for the left hemisphere insult group, these measures were also entered into correlational analyses and between groups comparisons. There was some suggestion that the two hemispheric insult groups showed higher correlations of verbal memory with reading than did the medical control group, but the between groups comparisons produced only two differences that achieved statistical significance (there were higher correlations of verbal memory in Year 2 with concurrent Neale reading in both hemispheric insult groups compared with the medical control group). The right hemisphere insult group tended to show lower correlations of visual memory with reading performance than the medical control or left hemisphere insult groups. However, only one between group comparison (between the right hemisphere insult group and the medical controls for the visual memory with Neale reading correlation in Year 2) achieved significance. It might be hypothesised that a right hemisphere injury could prevent visual processes playing a role in early literacy development, thus encouraging the child to make more use of phonological abilities and verbal memory. For the left hemisphere insult group, letter knowledge in conjunction with verbal memory skills may be the main contributors to beginning reading and spelling, with visual memory playing an additional modest part. Whatever, alternative skills the left hemisphere insult children were applying to their literacy attainments, they were clearly effective since these children had made a very promising start in developing reading and spelling skills. Whether they would be able to sustain this good rate of progress, in the absence of a strong phonology-literacy connection, is an issue for further research.

8.5 Conclusion

The powerful association between phonological awareness and literacy, originally demonstrated in a sample of 38 normal children, was replicated in both an alternative (medical) control group and a sample of children with right hemisphere insults. However, this association was considerably reduced in children who had left hemisphere insults but who nonetheless had no beginning reading or spelling problems. Thus, the phonology-literacy connection, while generally a robust one, may be disrupted by left hemispheric injuries. However, the capacity of the early injured brain to reorganise itself, and to compensate through reliance on alternative cognitive skills (such as letter knowledge and verbal memory), cannot be underestimated.

Chapter 9

Conclusions and a Model of Early Literacy Development

This thesis has explored the development of early literacy skills, and the cognitive abilities that contribute to them, in both neurologically normal children and a sample of children with unilateral brain injury. A model of normal literacy development was evolved that specified how phonological awareness, in relation to letter knowledge, influenced the acquisition of reading and spelling skills during the first two years at school. One way of testing the limits of such a model is to investigate what conditions need to be met before it is disrupted. Partly to this end, a sample of similarly-aged children with early acquired unilateral brain injury was studied. In addressing the issue of how effectively these children were able to acquire literacy and phonological skills in the face of cerebral injury, conclusions can be drawn about how and to what extent such abilities are preserved and prioritised within the developing and immature brain.

9.1 A Model of Normal Early Literacy Development

The study of 38 normal children from nursery through the first two years of infant school afforded the opportunity to develop a causal model of early reading and spelling development. Its point of departure was the previous research that had suggested that the two primary contributors to early literacy progress are phonological awareness and letter knowledge (c.f. Adams, 1990).

The present study explored, first, the nature of phonological awareness, by administering tests of phoneme identification and deletion, rhyming and sound blending to the normal sample on three separate occasions over a two-year period. Principal Components Analysis showed that in each year of the study, two relatively independent factors emerged. The tests of phoneme identification, phoneme deletion and sound blending loaded highly on one factor (the **segmentation** factor), while the tests of rhyme detection and production loaded highly on the second factor (the **rhyming** factor). Other researchers have hinted at there being two factors underlying phonological awareness, and indeed Goswami and Bryant's 1990 model of beginning reading hinges on such an assumption. However, this is, as far as is known, the first study to empirically demonstrate the independent existence of rhyming and segmentation subskills within the phonological domain.

The second aim of the study involving normal children was to explore, through Path Analysis, how phonological awareness influences early reading and spelling progress. During the first year at school, the segmentation factor significantly influenced both reading and spelling performance, while the rhyming factor did not. Letter knowledge made a separate and distinct contribution to literacy progress. When the product term, Letter Knowledge x Segmentation, was entered into the path analyses, it made an additional contribution, over and above the influence of its separate constituent skills, to reading and, in particular, spelling attainment. This finding provided confirmation of the "Phonological Linkage Hypothesis" (Hatcher, Hulme and Ellis, 1994) that states that phonological skills need to be meaningfully linked to the child's experience of print to maximise their benefit to reading and spelling.

During the children's second year at school, phonological awareness and letter knowledge made no direct contribution to reading. Instead, there was evidence that the children were using their existing and ever growing lexicon to promote further gains in reading. The findings were interpreted as being consistent with Ehri's (1992) conceptualisation of a developing sight vocabulary though visual-phonological connections. Having established the alphabetic principle during the first year at school (Frith, 1985), the children used this knowledge, together with their increasing awareness of orthographic regularities, to read words directly, without the need for repeated use of translation rules. During the second year at school, spelling showed a divergence from reading, in remaining phonologically dependent. Both rhyming and segmentation skills made significant contributions to second year spelling. In the terminology of Goswami and Bryant, rhyming would be expected to draw children's attention to onset-rime boundaries within words thus promoting the use of analogical principles, while segmentation skills contribute to phonemic awareness as children "sound out" words they are asked to spell.

The contribution of phonological awareness to reading and spelling was a specific one; no such connection was found in relation to oral or written arithmetic (after controlling for the effects of IQ and, in the case of written arithmetic, reading skill). Verbal memory, as measured by a digit span test, failed to contribute to literacy progress, while visual memory (for letter-like forms) briefly influenced spelling attainment during the first year at primary school.

Contrary to the hypothesis of Goswami and Bryant, rhyming failed to make a significant contribution to early reading skill at least as measured by standardised reading tests. However, the possibility, consistent with Goswami and Bryant's hypothesis, that rhyming's influence over reading is specific to children's ability to apply analogical principles in reading was explored in Chapter 3 of the thesis. An experiment, involving a modification of the paradigm adopted by Goswami in her extensive studies of analogy, showed that children as young as six years can apply analogical principles to unknown words after being trained to criterion on a clue word that shared the same rime. However, this effect was less pronounced, though still significant, in children who did not have the clue word exposed when the unknown words were presented. The children who showed the most marked analogy effect were those who were able to refer back to the clue word when asked to read the unknown words.

After controlling for whether or not the clue was exposed at post-test, the major contributor to analogising was concurrent rhyming ability. Segmentation skills did not influence analogising. Moreover, although there was the relationship between rhyming ability and the use of analogical principles in reading at age 6, this "special" link between early rhyming (in Years 1 and 2) and later reading, as hypothesised by Goswami (1990), was not confirmed. Finally, it should be noted that in this experiment, few non-readers were able to demonstrate an analogy effect. Thus, some minimum decoding skill at the level of the phoneme is needed before children can analogise (Ehri and Robbins, 1992).

The findings of the longitudinal and analogy studies offer partial support for Goswami and Bryant's 1990 view of early reading development. The present model concurs with that of Goswami and Bryant in postulating, and indeed empirically demonstrating, the existence of two separate subskills (rhyming and segmentation) underlying phonological awareness. In keeping with their model, rhyming and segmentation appeared to exert different influences over early reading and spelling development. It is also agreed that reading and spelling may proceed along different routes during the first years at primary school.

However, some aspects of the Goswami and Bryant model failed to stand up to empirical test. In the latest refinement of the model (Goswami, 1993), now termed an "interactive analogy model of reading development", Goswami draws on the (still controversial) assumption that onset-rime awareness precedes phonemic awareness. She proposes that it is analogies, based on onset-rime units, that provide a useful entry strategy to reading. So, beginning readers know that a word like "plum" has at least two sounds i.e. "pl" (onset) and "um" (rime). The interactive analogy model views reading development as the increasingly refined process of lexical analogy. Early orthographic recognition units may have fairly gross level of phonological underpinning (onsets and rimes), reflecting the level of phonological awareness at school entry. However, as reading develops and is taught, phonological underpinning increasingly reflects phonemic knowledge. The growing refinement of knowledge about spelling-sound relationships will eventually result in the underpinning of all the constituent phonemes within words. Goswami's model is quite different a conceptualisation to that of the "direct mapping" hypothesis proposed by Ehri (1992) and developed further by Rack, Hulme, Snowling and Wightman (1994). Ehri has suggested that young children set up partial associations between letters and phonemes within words, and that they typically attend to initial and final phonemes i.e. "p..m" in "plum". Rack et al. have extended this concept by empirically demonstrating that young children have access, at an implicit level, to representations that, while incomplete, may be even more fine-grained than individual phonemes.

The current model, with its emphasis on the early contribution of segmentation skills and letter-sound connections to reading, shares more in common with the direct mapping hypothesis than with Goswami's latest model. It departs from the Goswami model in, first, proposing a different time course of the relative contributions of rhyming and segmentation to reading and spelling, and, second, in highlighting the significance of other contributory processes in literacy development. Importantly, it is proposed that it is children's segmentation ability, interacting with letter knowledge, that enables them to establish the alphabetic principle and so begin to develop reading and spelling skills shortly after they enter school. Rhyming, reflecting onset-rime awareness, exerts its influence on reading (by analogy) and on spelling in the following year. Analogical skills enter the reading development process later than do the application of at least some individual grapheme-to-phoneme relationships; in turn children need some basic level of reading skill before being able to apply analogical principles. The data presented in this thesis suggest that Goswami has overestimated the influence of rhyme, onset-rime and of analogy in beginning reading development, and in so doing failed to give due consideration to other phonological awareness skills (notably segmentation), or to other types of learned knowledge (letter-sound connections). While analogising can be readily demonstrated in children as young as six years, it is a skill that they may need to be explicitly taught, or at any rate prompted to use, rather than one they can apply spontaneously.

9.2 The Acquisition of Language, Phonology and Literacy Skills in Hemiplegic Children

The study of phonological skills and literacy development in children with focal brain injuries has permitted a number of theoretical, practical and clinical questions to be addressed. Thus, 38 children with unilateral brain injury of pre- or peri-natal origin were studied longitudinally over a two-year period, and their performance on a range of cognitive and reading related tests compared to that of 20 age-matched controls with chronic medical, but non-telencephalic, conditions. The brain-injured children were further subdivided according to hemispheric side of insult (left versus right) and presence or absence of seizures.

Preliminary analyses focused on Verbal, Performance and Full Scale IQ functioning within the hemispheric-injured and medical control groups. The failure to demonstrate marked decrements in cognitive functioning in the presence of a confirmed hemispheric insult, unaccompanied by seizures, suggested that the early-injured brain has a remarkable capacity for compensation. That said, there was a tendency for Performance (visuospatial) functions to be selectively impaired, even in the seizure-free patients. The absence of laterality effects on IQ supported the hypothesis of the equipotentiality of the two hemispheres for the development of at least gross language skills.

Over the two years of the study, the IQs of the hemispheric-injured children showed remarkable stability. The selective impairment of visuospatial functions could not readily be explained in terms of the reduced motor abilities of the hemiplegic children, but was thought to be a response to ongoing organisation processes. The results concurred with Teuber's cognitive crowding hypothesis. Thus, language skills are preserved within the early-injured brain, irrespective of side of injury, through a process of reorganisation of function within the remaining intact regions. However, this preservation may be achieved at the expense of other aspects of cognitive functioning, namely visuospatial functions. In the case of a left hemisphere injury, language skills are prioritised in the competition for neural space, and so are effectively spared, at least at a gross level. The reorganisation of language may take place through **inter**-hemispheric (to the right) or **intra**-hemispheric (within the left) transfer of language, or even a combination of both. However, to accommodate this reorganisation, other skills are assigned a lower order of priority and their development is consequently arrested or degraded. Since the Performance IQ of the seizure-free left hemisphere patients was selectively lowered, it is suggested that a degree of inter-hemispheric transfer of language function had taken place, as opposed to there being exclusively intra-hemispheric transfer which would not predict a detrimental effect on Performance IQ. In the case of a right hemisphere injury, the selective lowering of the Performance IQ is a direct consequence of damage to those regions specialised for visuospatial processing.

The presence of seizures had a marked deleterious effect on the hemiplegic children's verbal and non-verbal intelligence; when specific cognitive skills were subsequently studied, it was, therefore, necessary to enter IQ as a covariate in the analyses.

The availability of handedness and dichotic listening data permitted the study of the hemispheric representation of language within the hemiplegic sample. Early left hemisphere injury resulted in left-handedness and a reduced right-ear advantage, this being indicative of a tendency toward greater right hemisphere processing of language within this group. The right hemisphere shift was noted to be especially pronounced in the children with left hemisphere insult and seizures.

In spite of the evident reorganisation processes, assessment of the children's language skills did not reveal any marked detrimental effect of a hemispheric injury on language development, after controlling for IQ. However, one subgroup of the hemiplegic sample had additional selective difficulties that could not be accounted for IQ differences; these were the children with left hemisphere injuries with seizures. These children performed significantly below the seizure-free left hemisphere group and the right hemisphere with seizures group on two separate language measures (of receptive vocabulary and expressive sentence formulation).

When phonological awareness was studied in the hemiplegic sample, it was found that the presence of a unilateral lesion, irrespective of side of insult, had no deleterious effects on phonological awareness development, other than those that might be accounted for by IQ variation. There is thus, evidence that phonological skills are preserved in the early-injured brain, even when damage is to the left hemisphere. The failure to uncover the two independent subskills of rhyming and segmentation in the hemispheric insult groups makes it tempting to speculate that phonological awareness in such children may not be as refined nor as differentiated as in normal populations; this could have implications for these children's ability to subsequently develop specific reading and spelling strategies.

However, the presence of a unilateral lesion, again irrespective of side of insult, did not impair literacy or numeracy skills, provided the injury was not accompanied by seizures. In fact, the seizure-free children, especially those with left hemisphere injuries, were making remarkably good educational progress. However, the left hemisphere group with seizures was particularly disadvantaged in reading and arithmetical attainments relative to the seizure-free left hemisphere group (and in arithmetic, relative also to the right hemisphere group with seizures). This was an effect over and above that explicable in terms of the lower IQ of the children with seizures.

The finding that seizures in left hemisphere insult patients resulted in selective deficits in language and educational functioning leads one to speculate that seizures (and/or medication) disrupt the capacity of the left-injured brain to undergo the necessary functional reorganisation of language. The right hemisphere or the remaining intact regions of the left hemisphere may under certain (optimal) conditions take over the successful processing of language skills. However, seizures interfere with the reorganisation necessary to achieve this. Two possible mechanisms were discussed. The first draws on the finding from the dichotic listening data that the left hemisphere with seizures patients had the lowest mean laterality coefficient, an observation consistent with there being a greater degree of right hemisphere processing of language in this group. If it is assumed that a pronounced shift towards a left-ear advantage is associated with a greater extent of lesion, then the left hemisphere with seizures patients should have less neural space for language processing in the left hemisphere. The result is an enforced shift towards right hemisphere processing of language. There is thus a double disadvantage i.e. reduced neural capacity for language processing in the left hemisphere **and** the seizure-induced disruption of reorganisation processes in the right hemisphere. The second mechanism hypothesises that the reduced neural capacity for language function arises from the "spread" effect of seizures, such that both left and right hemisphere processing is impaired.

It is proposed that a unilateral hemispheric injury, provided that it is incurred early in life and is not accompanied by seizures, produces few detrimental effects on either spoken or written language processing. The relatively plastic developing brain has sufficient compensatory resources to enable effective functional reorganisation within the remaining neural space. This is true even when the injury is to the left hemisphere, in which damage during adult life results in specific language deficits. These findings support the argument developed by Bates (1992): "there is enormous plasticity in the brain regions that can support language ... and the areas responsible for language learning are not necessarily the same regions that mediate use and maintenance of language in adults" (p. 182). She goes on to conclude that language learning is not highly "domain-specific", but instead based on a relatively plastic mix of neural systems that also serve other functions. Vargha-Khadem (1993) discusses the mechanisms of plasticity and progressive lateralisation as working in opposition to each other during childhood. When a lateralised lesion is incurred early, as in the present study, then it is lateralisation of function that is sacrificed to plasticity and reorganisation. For lesions sustained later in life, lateralisation becomes progressively more prominent and plasticity is reduced, with the result that increasingly specific cognitive deficits arise from a localised cerebral insult.

The present study uncovered two limiting factors to successful reorganisation of function. First, the presence of seizures had a general depressing effect on cognitive function (IQ). The second limiting factor pertained to side of injury. Within the seizure sample, there was a particularly disadvantaged subgroup: children with left hemisphere insult. These children showed additional deficits in receptive and expressive language functioning and in early reading and numeracy skills, over and above those accounted for by their lower IQs. It was argued that, in the presence of a left hemisphere injury, seizures disrupt the capacity of the right hemisphere or the remaining intact regions of the left hemisphere to successfully assume language skills. Researchers participating in the US longitudinal study have also made the observation that the majority of children in their sample with unilateral lesions develop language apparently normally; however, there is an as yet unspecified subset of children that appears to have considerable language difficulties (Bates, 1993, personal communication). The present study has been able to delineate some of the factors that might account for the variability in cognitive outcome of children with unilateral lesions.

The strong association between phonology and reading originally demonstrated in a normal sample of children was successfully replicated in both an alternative normal (medical control) group and a sample of seizure-free children with right hemisphere insults. This suggests that the phonology-reading connection is indeed a strong and meaningful one, widely demonstrable, and indeed impervious to the disruption that would be expected to be caused by at least some cerebral insults. However, this is not to say that there might not be limits beyond which this otherwise strong association breaks down. The correlations between phonological awareness and reading skills were reduced in children who had (seizure-free) left hemisphere insults. These children acquired early reading skills perfectly well, but it seemed that they did not use phonological processes for promoting literacy development to the extent and in the same way as did the control or right hemisphere insult children. One might speculate that the left hemisphere is uniquely specialised, not so much for the development of phonological awareness and literacy skills per se, but rather for their successful interaction and integration. These findings suggest a limit to the capacity of the developing brain to compensate for language functions (even in the absence of seizures), and that this limit might specifically relate to integrative functions. It is, important to confirm these findings in larger samples of brain injured children (including those with seizures).

To what extent the left hemisphere insult children would be able to sustain their commendable rate of reading progress in the absence of a strong phonology-reading connection is a matter for follow-up research. The findings that the left hemisphere group showed, first, higher correlations of letter knowledge with reading than the right hemisphere group, and second, higher correlations of verbal memory with reading than the medical control group, suggests that these children may be making, apparently successful, use of alternative skills to promote their early reading development. The remarkable capacity of the functionally plastic early-injured brain to reorganise itself and to consequently compensate through reliance on alternative strategies and knowledge cannot be underestimated.

9.3 Conclusions

In this thesis, a new model of early reading development relating specific phonological awareness skills (rhyming and segmentation) to literacy processes has been proposed. In this model, phonological segmentation interacts with letter knowledge in its influence on the first year of learning to read and spell. Rhyming exerts an influence in the following year through its effect on spelling and on the use of analogical skills in reading. The study of a group of similarly-aged children with early-acquired unilateral brain injuries suggests that the phonology-reading connection, demonstrated in normal children, is also present in children with right hemisphere injuries. However, this connection may be reduced in children with left hemisphere insults who nonetheless read well. Children with left hemisphere insults may use alternative skills and knowledge to promote their early reading acquisition. Over and above these trends, the presence of seizures produces generalised impairment of cognitive functioning, and, in the case of children with left hemisphere insults, additional selective language deficits.

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Appendix 2.1 - Phonological Awareness Test Stimuli

Rhyme Detection Test

Demonstration Stimuli	Response Items		
cat	fish	gun	**hat**
ball	**wall**	bell	bag
chip	cup	**ship**	cheese

Test Stimuli	Response Items		
boat	foot	bike	**coat**
key	cow	**tree**	door
chair	car	table	**bear**
house	**mouse**	horse	window
head	hand	**bed**	eye
bell	bottle	dress	**shell**
sock	clown	**clock**	shoe
train	**rain**	tractor	spoon
egg	bag	spoon	**leg**
car	**star**	bike	cake

Correct response items appear in bold type

Appendix 2.1 - Phonological Awareness Test Stimuli (cont)

Phoneme Identification

Demonstration Items

Wa-tch

Ca-t

Test Items

Hor-**se**

Fi-**sh**

Kni-**fe**

Shi-**p**

Bo-**ne**

Car-**d**

Ga-**te**

Do-**g**

Correct phoneme to be supplied by the subject appears in bold type

Appendix 2.1 - Phonological Awareness Test Stimuli (cont)

Phoneme Deletion Test

Demonstration Items

Bus

Sad

Pie

Cow

Test Items

Meat

Bear

Hat

Sit

Jam

Tin

Cake

Toy

Cup

Man

Phoneme to be deleted by the subject appears in bold type

Appendix 2.2 - Written Arithmetic Test Stimuli

1) *Which number is the bigger?*

6	8	/1
23	32	/1

2) *Write the two numbers that come next.*

7, 8, 9, ?, ?	/2
26, 27, 28, ?, ?	/2

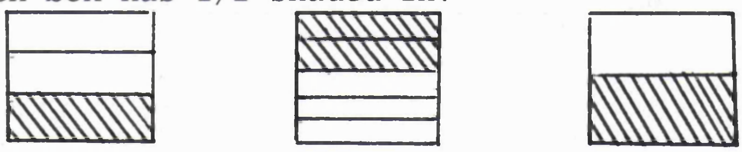
3)

4 + 3 = ?	/1
7 = 6 = ?	/1

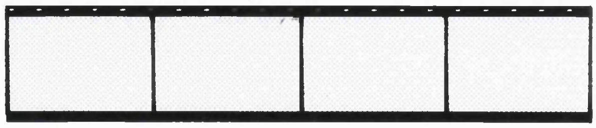
4)

10 - 6 = ?	/1
12 - 4 = ?	/1

5) *Which box has 1/2 shaded in?*



Shade in a quarter of the box



/3

6) *Put circles around the trees to make groups of 7. How many are left over?*

/2

Appendix 2.2 - Written Mathematics Test Stimuli (cont)

7) 5 + 2 = 7

Write in two other pairs of numbers that also add up to 7

? + ? = 7   ? + ? = 7   /2

8)
```
   14
 + 15
   ??      /1

   56
 - 42
   ??      /1
```

9)
```
   24
  +36
   ??      /2
```

10) *Count by 2s* /2

by 5s /2

by 10s /2

Total /27

/n - indicates marks allocated to each item.

Orally administered instructions are given in italics where relevant.

Appendix 3.1 - Analogy Experiments - Experimental materials, including Kucera-Francis word frequencies

List A

Clue	Analogy	Control
ring (47)	king (88)	gain (74)
	sing (34)	sign (94)
	wing (18)	rink (2)
	ping (0)	rang (21)
back (967)	pack (25)	cake (13)
	sack (8)	beak (0)
	rack (9)	bark (14)
	track (38)	crab (0)
land (217)	sand (28)	lean (20)
	grand (48)	nail (6)
	hand (431)	lend (14)
	band (53)	bald (5)
told (413)	gold (52)	doll (10)
	sold (47)	bolt (10)
	cold (171)	toad (4)
	hold (169)	lost (173)
neat (21)	meat (45)	team (83)
	heat (97)	late (179)
	beat (68)	tent (20)
	seat (54)	lane (30)

Appendix 3.1 - Analogy Experiments (cont)

List B

Clue	Analogy	Control
rang (21)	bang (7)	gain (74)
	hang (26)	ring (47)
	sang (29)	near (198)
	gang (22)	barn (29)
sock (4)	lock (23)	cook (17)
	dock (8)	cost (229)
	cock (5)	soak (7)
	rock (75)	sick (51)
sent (145)	dent (2)	nest (20)
	lent (5)	seen (279)
	went (507)	neat (21)
	rent (21)	step (131)
mind (325)	find (399)	mint (7)
	kind (313)	mend (2)
	bind (4)	tied (-)
	wind (63)	dine (2)
tail (24)	sail (12)	late (179)
	fail (37)	tile (16)
	mail (47)	wait (38)
	rail (16)	tall (55)

Appendix 5.1 - Medical History Questionnaire

Name of Child: ----------------

A. Pregnancy and Delivery

a) Approximate duration of pregnancy ....
b) Any complications during pregnancy ....
c) Was the labour spontaneous or induced ....
d) Were there any birth complications ....
e) What was the birth weight ....
f) What was the Apgar score ....
g) Did the child suffer from jaundice or any other postpartum complication? ....
h) What was the postpartum period spent in hospital? ....
Was the child discharged with the mother? ......

B. Nature of the Hemiplegia

Do you consider the child's hemiplegia to be
Congenital ...... perinatal ...... acquired .....
If acquired, at what age? ....
Also, if acquired, what episode or incident precipitated the onset of symptoms? ....

C. Diagnosis of the Hemiplegia

When was the weakness first noted? ....
By parent? ....
Medically? ....
Was the weakness in the hand? ....
leg? ....
or both? ....

Appendix 5.1 - Medical History Questionnaire (cont)

D. Developmental Milestones (if known)

At what age did the child:
Smile ....
Reach ....
Sit ....
Crawl ....
Walk ....
Say his/her first words ....

E. Presence of Seizures

Has the child suffered from seizures? ....
from febrile convulsions? ..
If yes, what type ....
frequency ....
duration ....
When was the first seizure? ....
When was the last or most recent seizure? ....
Is the child on medication? ....
If so, what drug/s is/are being used, and in what dosage? ....
What other drugs have been employed in the past, and in what dosage? ....
Is the child's drug level being monitored? ....
When was the last blood test and what was the result?
....

Appendix 5.1 - Medical History Questionnaire (cont)

F. History of Surgery and Neurological Assessment Procedures

Has the child had a CT scan? ....
If yes, where and when was this done? ....
What did it show? (Please enclose a copy of the CT scan report if possible) ....
Has the child had an EEG? ....
If yes, where and when was this done? ....

What did it show? (Please enclose a copy of the EEG report if possible) ....
Has the child been subjected to orthopaedic treatment or surgery? ....
Please give details of any operations performed .....
Have there been any other illnesses which have required hospital admission? ....
If yes, please give details ....

G. Names of Other Professionals Involved

E.g. speech therapists, physiotherapists ....

Thank you for your help.

Appendix 5.2 - The hemiplegic sample - Diagnosis, seizure status, and neuroradiology

Subject	Hemispheric Side	Seizure Status	Radiology
SP	Left	Seizure to '89	CT ('86) normal, EEG ('86, '90) - mildly abnormal
HS	Left	Non Seizure	CT ('87) Left side change consistent with vessel block
SF	Left	Non Seizure	Clinical diagnosis only.
AT	Left	Seizure (ongoing)	CT ('85) Left hemiatrophy, EEG('85, '90) mainly left temporal discharges.
TW	Left	Non Seizure	Clinical diagnosis only.
CV	Right	Seizure (on going)	CT ('87) hemiatrophy of right cortex. EEG ('87) active spikes at right central Sylvian region.

Appendix 5.2 - The Hemiplegic Sample (cont)

Subject	**Hemispheric Side**	**Seizure Status**	**Radiology**
KT	Right	Non	CT ('86) right extensive density lesion, enlarged right ventricle.
JL	Left	Non Seizure	CT ('86) left dural haematoma,low density region at left middle cerebral artery.
LT	Left	Non Seizure	CT ('85) porencephalic cyst in left post frontal region.
RS	Left	Non Seizure	Clinical diagnosis only.
TS	Right	Non Seizure	Clinical diagnosis only.
CP	Left	Non Seizure	Clinical diagnosis only.
DP	Right	Non Seizure	Clinical diagnosis only.
MH	Left	Seizures (ongoing)	CT ('85) left hemiatrophy EEG ('90) sharp waves in left frontal and central regions.

Appendix 5.2 - The Hemiplegic Sample (cont)

Subject	Hemispheric Side	Seizure Status	Radiology
PM	Right	Seizure (at 3y)	EEG ('88) minor abnormalities.
JL	Right	Non Seizure	Clinical diagnosis only.
SM	Right	Non Seizure	CT ('85) right por- encephalic cyst nr middle cerebral artery.
AC	Right	Non Seizure	Clinical diagnosis only.
TM	Right	Seizure	CT ('89) right hemiatropy EEG ('85, '87, '90) Epileptiform bursts over over right centro-temporal & fronto-central regions.
AD	Left	Non Seizure	Ultrasound ('84) left intraventricular haemorrhage
FH	Right	Seizure	EEG ('86) asymmetry of background activity Porencephaly due to thrombosis of right cerebral artery.

Appendix 5.2 - The Hemiplegic sample (cont)

Subject	Hemispheric Side	Seizure Status	Radiology
SD	Left	Non Seizure	Clinical diagnosis only.
JC	Right	Non Seizure	CT ('84) distortion & displacement of right lateral ventricle, ?atrophy due to early infarct.
LB	Left	Non Seizure	Clinical diagnosis only.
SD	Left	Non Seizure	EEG ('90) normal. CT ('90) enlarged left lateral ventricle, low density area in left post-frontal/parietal region.
GC	Left	Non Seizure	Skull X-Ray, ultrasound (84) hemispheric asymmetry.
AB	Left	Non Seizure	Clinical diagnosis only.

Appendix 5.2 - The Hemiplegic Sample (cont)

Subject	Hemispheric Side	Seizure Status	Radiology
BA	Right	Non Seizure	CT ('86) marked dilatation of body & posterior horn of right lateral ventricle, smaller right hemisphere.
SF	Right	Non Seizure	Ultrasound ('85) normal.
HA	Left	Non Seizure	Clinical diagnosis only.
CB	Left	Seizures (ongoing)	CT ('84) enlarged left ventricle, loss of brain substance on left EEG ('84) unclear.
OI	Left	Non Seizure	Clinical diagnosis only.
EH	Left	Seizures (ongoing)	EEG ('87) moderate ab-normalities to left.
BL	Right	Non Seizure	CT ('84) large CSF occupying area in right frontal region & near to right anterior cerebral artery.

Appendix 5.2 - The Hemiplegic Sample (cont)

Subject	Hemispheric Side	Seizure Status	Radiology
JK	Left	Seizure (Grand Mal '90)	CT ('86) left hemiatrophy, migrational abnormality. EEG ('86) abnormal discharges in left hemisphere.
JH	Left	Seizures (ongoing)	CT ('86) left porencephalic cyst, defect in left frontotemporal region, dilated left ventricle. EEG ('90) generalised left abnormalities, focal spike discharge in left posterior quadrant.
DC	Left	Seizures	CT ('86) EEG ('86) hypsorhythmia.
MB	Right	Non Seizure	Clinical diagnosis only.

CT - Computerised Tomography Scan.
EEG - Electroencepalography.
CSF - Cerebrospinal fluid.
Dates of investigations given in parentheses, where known.

Appendix 5.3 - Tests administered and measures taken in Years 1 to 3 of the study for the hemiplegic and medical control groups

Year 1

Test	Measure
WPPSI IQ Test	Full Scale IQ (8 subtests) Verbal IQ (4 subtests) Performance IQ (4 subtests)
WISC-R Digit Span	Total weighted score (/28)
Goulandris Visual Memory	Total correct recalled items /24
TROG	Total items passed (/80)
Bus Story	Information, total raw score (/54) Average sentence length
BPVS	Total correct (/150)
Rhyme Detection Test	Total correct (/10)
Rhyme Production Test	Total rhymes produced
Phoneme Identification Test	Total correct phonemes (/8)
Phoneme Deletion	Total correct (/10)
Letter Naming	Total correct (/26)
BAS Reading Test	Total words read correctly - up to 3 stories (/151)
Handedness Inventory	Total score (range 18 - 90)

Appendix 5.3 - Tests and Measures (cont)

Year 2

Test	Measure
WISC-R Digit Span	Total weighted score (/28)
Goulandris Visual Memory	Total correct recalled items (/24)
Picture Naming Test	Total correct weighted score (/120)
CELF-R Formulated Sentences	Total raw score (/60)
Word Fluency	Total number of words produced
Rhyme Detection Test	Total correct (/10)
Rhyme Production Test	Total rhymes produced
Phoneme Identification Test	Total correct phonemes (/8)
Phoneme Deletion	Total correct (/10)
ITPA Sound Blending	Total correct (/32)
Letter Naming	Total correct (/26)
BAS Reading Test	Total words correct (/90)
Neale Reading Test	Total words correct - up to 3 stories (/151)
Schonell Spelling Test	Total words correct (/100)

Appendix 5.3 - Tests and Measures (cont)

Year 3

Test	Measure
WISC-R IQ Test	Full Scale IQ (4 subtests)
	Verbal IQ (2 subtests)
	Performance IQ (2 subtests)
WISC-R Digit Span	Total weighted score (/28)
Goulandris Visual Memory	Total correct recalled items (/24)
BPVS	Total correct (/150)
Rhyme Detection Test	Total correct (/10)
Rhyme Production Test	Total rhymes produced
Phoneme Identification Test	Total correct phonemes (/8)
Phoneme Deletion Test	Total correct (/10)
ITPA Sound Blending	Total correct (/32)
Letter Naming	Total correct (/26)
BAS Reading Test	Total words correct (/90)
Neale Reading Test	Total words read correctly - up to 3 stories (/151)
Schonell Spelling Test	Total words correct (/100)
WISC-R Arithmetic Subtest	Scaled score (1 - 19)
Written Mathematics Test	Total items correct (/27)
Dichotic Listening Test:	
Monaural Condition	Total left ear recall (/18)
	Total right ear recall (/18)
	Total for both ears (/36)
Dichotic Condition	Total left ear recall (/36)
	Total right ear recall (/36)
	Total for both ears (/72)
	Laterality coefficient (-1/+1)

Appendix 6.1 - Language Data - Series 1 Analyses - The effects of hemispheric side of insult and of seizures on language test performance (non-significant results)

Test	**Factor**	**F**	**p=**
Year 1:			
BPVS	Side	0.11	.75
	Seizure	1.33	.26
TROG	Side	0.01	.94
	Seizure	0.09	.76
	Side x Seizure	3.55	.07
Bus Story (Information)	Side	0.31	.58
	Seizure	0.02	.90
	Side x Seizure	1.28	.27
Bus Story (Average sentence length)	Side	0.19	.67
	Seizure	0.00	.96
	Side x Seizure	0.63	.43
Year 2:			
Formulated Sentences	Side	0.02	.88
Word Fluency	Side	0.00	.98
	Seizure	1.26	.27
	Side x Seizure	2.58	.12
Picture Naming	Side	1.30	.26
	Seizure	0.03	.86
	Side x Seizure	0.33	.57
Year 3:			
BPVS	Side	0.00	.98
	Seizure	0.01	.91
	Side x seizure	1.58	.22

Appendix 6.2 - Language Data - Series 2 Analyses - The effects of hemispheric side of insult and of seizures on language functioning, in comparison with the medical control group (non-significant results)

Test	Factor	F	p=
Year 1:	**HNS, HS, MC**		
TROG	Main Group	1.11	.34
Bus Story (Information)	Main Group	0.88	.42
Bus Story (Average Sentence length)	Main Group	2.66	.08
Year 2:	**HNS, HS, MC**		
Picture Naming	Main Group	0.52	.60
Word Fluency	Main Group	2.27	.11
Year 3:	**HNS, HS, MC**		
BPVS	Main Group	2.28	.11

Appendix 6.2 - Language Data - Series 2 Analyses (cont)

Test	**Factor**	**F**	**p=**
Year 1:	**LNS, RNS, LS, RS**		
BPVS	LNS+RNS vs LS+RS	0.06	.81
	LNS vs RNS	1.64	.21
	RNS vs RS	2.23	.14
Year 2:	**LNS, RNS, LS, RS**		
Formulated Sentences	LNS+RNS vs LS+RS	1.66	.21
	LNS vs RNS	2.67	.11
	RNS vs RS	0.60	.44
Year 1:	**LNS, RNS, MC**		
BPVS	RNS vs MC	1.89	.18
	LNS vs RNS	1.72	.20
Year 2:	**LNS, RNS, MC**		
Formulated Sentences	Main Group	1.97	.15

Appendix 6.3 - Language Data - Series 3 Analyses - BPVS and change over time, Years 1 and 3 (non-significant results)

Test	Factor	F	p=
Average Scores	**LNS, RNS, MC**		
	RNS vs MC	2.16	.15
	LNS vs RNS	1.31	.26
Change Scores	**LNS, RNS, MC**		
	Main Group	0.63	.54
Average Scores	**LNS, RNS, LS, RS**		
	Main Group	1.68	.19
Change Scores	**LNS, RNS, LS, RS**		
	Main Group	0.98	.41

Appendix 7.1 - Phonological Awareness Data - Series 1 Analyses - The effects of hemispheric side of insult and of seizures on phonological awareness (non-significant results)

Test	**Factor**	**F**	**p=**
Year 1			
Rhyme Detection	Side	0.26	.61
	Seizure	1.31	.26
	Side x Seizure	0.08	.78
Rhyme Production	Side	1.13	.30
	Seizure	0.41	.52
	Side x Seizure	1.03	.32
Phoneme Identific.	Side	0.15	.70
	Seizure	0.12	.73
	Side x Seizure	1.86	.18
Phoneme Deletion	Side	0.55	.46
	Seizure	0.01	.95
	Side x Seizure	0.04	.85
Year 2			
Rhyme Detection	Side	0.63	.43
	Seizure	0.08	.78
	Side x Seizure	0.90	.35
Rhyme Production	Seizure	0.02	.89
Phoneme Identific.	Side	0.07	.80
	Seizure	0.10	.76
	Side x Seizure	0.28	.60
Phoneme Deletion	Side	0.27	.61
	Seizure	0.00	.99
	Side x Seizure	2.14	.15

Appendix 7.1 - Phonological Awareness Data - Series 1 Analyses (cont)

Test	**Factor**	**F**	**p=**
Sound Blending	Side	1.28	.27
	Seizure	0.02	.90
	Side x Seizure	0.44	.51
Year 3			
Rhyme Detection	Side	2.38	.13
	Seizure	0.05	.82
	Side x Seizure	0.74	.40
Rhyme Production	Side	0.01	.91
	Seizure	0.00	.96
	Side x Seizure	2.53	.12
Phoneme Identific.	Side	1.45	.24
	Seizure	0.01	.91
	Side x Seizure	1.09	.30
Phoneme Deletion	Side	0.07	.80
	Seizure	0.03	.87
	Side x Seizure	1.01	.32
Sound Blending	Side	1.28	.26
	Seizure	0.46	.50
	Side x Seizure	0.33	.57

Appendix 7.2 - Phonological Awareness Data - Series 2 Analyses - The development of phonological awareness in hemiplegic children (non-significant results)

Test	**Factor**	**F**	**p=**
Rhyme Detection (average scores)	Main Group	0.10	.91
Rhyme Detection (change scores)	Main Group	1.02	.40
Rhyme Production (average scores)	Main Group	0.06	.94
Rhyme Production (change scores)	Main Group	0.94	.40
Phoneme Identific. (average scores)	Main Group	0.39	.68
Phoneme Identific. (change scores)	Main Group	0.25	.91
Phoneme Deletion (average scores)	Main Group	0.07	.93
Phoneme Deletion (change scores)	Main Group	0.12	.97
Sound Blending (average scores)	Main Group	0.00	.99
Sound Blending (change scores)	Main Group	1.40	.26

Appendix 7.3 - Phonological Awareness Data - Series 3 Analyses - Results of analyses of variance of factor scores for all five groups

Year	F	d.f.	p=
1	1.18	4,55	.33
2	1.00	4,55	.42
3	1.06	4,55	.39

Appendix 7.4 - Attainment Data - Series 1 Analyses - The effects of hemispheric side of insult and of seizures on attainments (non-significant results).

Test	Factor	F	p=
Year 1			
Letter Naming	Side	2.33	.14
	Seizure	0.99	.33
	Side x Seizure	0.80	.38
Year 2			
Letter Naming	Seizure	0.58	.45
	Side x Seizure	0.01	.93
BAS Reading	Side	2.02	.16
	Seizure	2.96	.09
Neale Reading	Side	2.30	.14
	Seizure	1.90	.18
Spelling	Side	0.65	.43
	Seizure	0.41	.52
Year 3			
Letter Naming	Side	0.26	.62
	Seizure	0.48	.49
	Side x Seizure	0.75	.39
BAS Reading	Side	1.09	.30
	Seizure	1.44	.24
Neale Reading	Side	3.39	.07
	Seizure	1.98	.17
Spelling	Side	1.25	.27
	Seizure	0.68	.42

Appendix 7.4 - Attainment Data - Series 1 Analyses (cont)

Test	Factor	F	p=
WISC-R Arithmetic	Side	0.92	.34
	Seizure	0.77	.39
Written Maths	Side	0.09	.77
	Seizure	1.49	.23

Appendix 7.5 - Attainment Data - Series 2 Analyses - The development of reading and spelling skills in the seizure-free hemiplegic groups (non-significant results)

Test	**Factor**	**F**	**p=**
Letter Knowledge (average scores)	Main Group	2.84	.07
Letter Knowledge (change scores)	Main Group	1.16	.32
BAS Reading (average scores)	LNS+RNS vs MC	0.61	.44
	RNS vs MC	0.38	.54
	LNS vs MC	4.00	.052
BAS Reading (change scores)	Main Group	1.36	.27
Neale Reading (average scores)	LNS+RNS vs MC	1.61	.21
	RNS vs MC	0.45	.51
Neale Reading (change scores)	Main Group	2.91	.07
Schonell Spelling (average scores)	Main Group	2.97	.07
Schonell Spelling (change scores)	Main Group	0.89	.42

Appendix 7.6 - Attainment Data - Series 3 Analyses - The development of reading and spelling skills within the hemiplegic samples (non-significant results)

Test	**Factor**	**F**	**p=**
Letter Knowledge (average scores)	Main Group	1.00	.40
Letter Knowledge (change scores)	Main Group	2.29	.09
BAS Reading (average scores)	RNS+LNSvsRS+LS	0.25	.62
	RNS vs RS	1.41	.24
	RS vs LS	2.39	.13
BAS Reading (change scores)	Main Group	1.27	.30
Neale Reading (average scores)	RNS+LNSvsRS+LS	0.40	.53
	RNS vs RS	1.75	.19
	RS vs LS	1.87	.18
Neale Reading (change scores)	Main Group	1.95	.14
Schonell Spelling (average scores)	Main Group	2.34	.09
Schonell Spelling (change scores)	Main Group	1.02	.39

Appendix 7.7 - Attainment Data - Series 4 Analyses - Analyses of the Arithmetic data (non-significant results)

Groups LNS, RNS and MC

Test	**Factor**	**F**	**p=**
WISC-R Arithmetic	RNS+LNSvsMC	0.11	.74
	RNS vs MC	2.82	.10
	LNS vs MC	1.40	.24
Written Maths	Main Group	0.76	.47

Groups LNS, RNS, LS and RS

Test	**Factor**	**F**	**p=**
WISC-R Arithmetic	LNS+RNSvsLS+RS	0.05	.83
Written Maths	Main Group	2.30	.09

Appendix 8.1 - Phonological Awareness and Literacy Attainments - Results of the Fisher's z transformation statistics analyses in group comparisons of the correlations of phonological awareness or letter knowledge with literacy attainment

Groups RNS and LNS (Right and left hemispheric hemiplegics)

Year 2 Phoneme Deletion with Year 2 Attainments Correlations:

BAS reading	$z = 1.04$, ns;
Neale reading	$z = 1.00$, ns;
Schonell spelling	$z = 0.24$, ns.

Year 2 Phoneme Deletion with Year 3 Attainments Correlations:

BAS reading	$z = 1.73$, ns;
Neale reading	$z = 2.48$, $p < .05$;
Schonell spelling	$z = 0.98$, ns.

Year 3 Phoneme Deletion with Year 3 Attainments Correlations:

BAS reading	$z = 1.60$, ns;
Neale reading	$z = 2.73$, $p < .01$;
Schonell spelling	$z = 1.56$, ns.

Year 2 Sound Blending with Year 2 Attainments Correlations:

BAS reading	$z = 2.30$, $p < .05$;
Neale reading	$z = 1.84$, ns;
Schonell spelling	$z = 0.96$, ns.

Year 2 Sound Blending with Year 3 Attainments Correlations:

BAS reading	$z = 1.42$, ns
Neale reading	$z = 1.98$, $p < .05$;
Schonell spelling	$z = 0.96$, ns.

Year 3 Sound Blending with Year 3 Attainments Correlations:

BAS reading	$z = 1.87$, ns
Neale reading	$z = 2.27$, $p < .05$;
Schonell spelling	$z = 1.22$, ns.

Appendix 8.1 - Phonological Awareness and Literacy Attainments (cont)

Groups RNS and LNS

Year 2 Letter Knowledge with Year 2 Attainments Correlations:

BAS reading	z = 1.42, ns;
Neale reading	z = 0.49, ns;
Schonell spelling	z = 0.33, ns.

Year 2 Letter Knowledge with Year 3 Attainments Correlations:

BAS reading	z = 1.24, ns;
Neale reading	z = 0.33, ns;
Schonell spelling	z = 0.73, ns.

Year 3 Letter Knowledge with Year 3 Attainments Correlations:

BAS reading	z = 1.02, ns;
Neale reading	z = 0.38, ns;
Schonell spelling	z = 0.60, ns.

Groups RNS and MC (Right hemispheric hemiplegics and medical controls):

Year 2 Phoneme Deletion with Year 2 Attainments Correlations:

BAS reading	z = 0.50, ns;
Neale reading	z = 0.66, ns;
Schonell spelling	z = 0.04, ns.

Year 2 Phoneme Deletion with Year 3 Attainments Correlations:

BAS reading	z = 0.45, ns;
Neale reading	z = 0.52, ns;
Schonell spelling	z = 0.09, ns.

Appendix 8.1 - Phonological Awareness and Literacy Attainments (cont)

Year 3 Phoneme Deletion with Year 3 Attainments Correlations:

BAS reading	$z = 0.48$, ns;
Neale reading	$z = 1.34$, ns;
Schonell spelling	$z = 1.07$, ns.

Groups RNS and MC:

Year 2 Sound Blending with Year 2 Attainments Correlations:

BAS reading	$z = 0.93$, ns;
Neale reading	$z = 1.36$, ns;
Schonell spelling	$z = 0.05$, ns.

Year 2 Sound Blending with Year 3 Attainments Correlations:

BAS reading	$z = 0.18$, ns;
Neale reading	$z = 0.05$, ns;
Schonell spelling	$z = 0.05$, ns.

Year 3 Sound Blending with Year 3 Attainments Correlations:

BAS reading	$z = 0.48$, ns;
Neale reading	$z = 0.57$, ns;
Schonell spelling	$z = 0.25$, ns.

Year 2 Letter Knowledge with Year 2 Attainments Correlations:

BAS reading	$z = 0.95$, ns;
Neale reading	$z = 0.77$, ns;
Schonell spelling	$z = 0.23$, ns.

Year 2 Letter Knowledge with Year 3 Attainments Correlations:

BAS reading	$z = 1.66$, ns;
Neale reading	$z = 1.36$, ns;
Schonell spelling	$z = 0.93$, ns.

Appendix 8.1 - Phonological Awareness and Literacy Attainments (cont)

Year 3 Letter Knowledge with Year 3 Attainments Correlations:

BAS reading $z = 1.09$, ns;
Neale reading $z = 0.98$, ns;
Schonell spelling $z = 0.75$, ns.

Groups LNS and MC (Left hemispheric hemiplegics and medical controls)

Year 2 Phoneme Deletion with Year 2 Attainments Correlations:

BAS reading $z = 1.74$, ns;
Neale reading $z = 0.41$, ns;
Schonell spelling $z = 0.33$, ns.

Year 2 Phoneme Deletion with Year 3 Attainments Correlations:

BAS reading $z = 1.41$, ns;
Neale reading $z = 2.02$, $p < .05$;
Schonell spelling $z = 0.56$, ns.

Year 3 Phoneme Deletion with Year 3 Attainments Correlations:

BAS reading $z = 1.31$, ns;
Neale reading $z = 1.64$, ns;
Schonell spelling $z = 0.56$, ns.

Year 2 Sound Blending with Year 2 Attainments Correaltions:

BAS reading $z = 1.61$, ns;
Neale reading $z = 0.59$, ns;
Schonell spelling $z = 1.18$, ns.

Year 2 Sound Blending with Year 3 Attainments Correlations:

BAS reading $z = 1.44$, ns;
Neale reading $z = 2.13$, $p < .05$;
Schonell spelling $z = 1.13$, ns.

Appendix 8.1 - Phonological Awareness and Literacy Attainments (cont)

Year 3 Sound Blending with Year 3 Attainments Correlations:

BAS reading	$z = 1.61$, ns;
Neale reading	$z = 1.97$, $p < .05$;
Schonell spelling	$z = 1.13$, ns.

Groups LNS and MC

Year 2 Letter Knowledge with Year 2 Attainments Correlations:

BAS reading	$z = 0.56$, ns;
Neale reading	$z = 1.33$, ns;
Schonell spelling	$z = 0.13$, ns.

Year 2 Letter Knowledge with Year 3 Attainments Correlations:

BAS reading	$z = 0.67$, ns;
Neale reading	$z = 1.15$, ns;
Schonell spelling	$z = 0.05$, ns.

Year 3 Letter Knowledge with Year 3 Attainments Correlations:

BAS reading	$z = 0.05$, ns;
Neale reading	$z = 1.54$, ns;
Schonell spelling	$z = 0.15$, ns.

Appendix 8.2 - Verbal Memory, Visual memory and Literacy Attainments - Results of the Fisher's z transformation statistic analyses in group comparisons of the correlations of verbal or visual memory with literacy attainments

<u>Groups RNS and LNS (Right and left hemispheric hemiplegics)</u>

<u>Year 2 Verbal Memory with Year 2 Attainment Correlations</u>

BAS reading	z = 0.11, ns;
Neale reading	z = 0.64, ns;
Schonell spelling	z = 0.38, ns.

<u>Year 2 Verbal Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.49, ns;
Neale reading	z = 1.27, ns;
Schonell spelling	z = 0.69, ns.

<u>Year 3 Verbal Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.60, ns;
Neale reading	z = 0.76, ns;
Schonell spelling	z = 0.38, ns.

<u>Year 2 Visual Memory with Year 2 Attainment Correlations</u>

BAS reading	z = 0.22, ns;
Neale reading	z = 0.93, ns;
Schonell spelling	z = 0.93, ns.

<u>Year 2 Visual Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.44, ns;
Neale reading	z = 0.33, ns;
Schonell spelling	z = 0.56, ns;

<u>Year 3 Visual Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.84, ns;
Neale reading	z = 0.89, ns;
Schonell spelling	z = 1.05, ns.

Appendix 8.2 - Verbal Memory, Visual memory and Literacy Attainments (cont)

<u>**Groups RNS and MC (Right hemispheric hemiplegics and medical controls)**</u>

<u>Year 2 Verbal Memory with Year 2 Attainment Correaltions</u>

BAS reading	z = 1.02, ns;
Neale reading	z = 2.48, $p < .05$;
Schonell spelling	z = 1.43, ns.

<u>Year 2 Verbal Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 1.20, ns;
Neale reading	z = 1.41, ns;
Schonell spelling	z = 1.36, ns.

<u>Year 3 Verbal Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.09, ns;
Neale reading	z = 0.27, ns;
Schonell spelling	z = 0.36, ns.

<u>Year 2 Visual Memory with Year 2 Attainment Correlations</u>

BAS reading	z = 1.84, ns;
Neale reading	z = 2.43, ns
Schonell spelling	z = 1.34, ns.

<u>Year 2 Visual Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.89, ns;
Neale reading	z = 1.00, ns;
Schonell spelling	z = 0.99, ns.

<u>Year 3 Visual Memory with Year 3 Attainment Correlations</u>

BAS reading	z = 0.48, ns;
Neale reading	z = 0.54, ns;
Schonell spelling	z = 0.23, ns.

Appendix 8.2 - Verbal Memory, Visual memory and Literacy Attainments (cont)

<u>**Groups LNS and MC (Left hemispheric hemiplegics and medical controls)**</u>

<u>Year 2 Verbal Memory with Year 2 Attainment Correlations</u>

BAS reading	$z = 1.05$, ns;
Neale reading	$z = 2.00$, $p < .05$;
Schonell spelling	$z = 1.56$, ns.

<u>Year 2 Verbal Memory with Year 3 Attainment Correlations</u>

BAS reading	$z = 0.44$, ns;
Neale reading	$z = 0.00$, ns;
Schonell spelling	$z = 0.77$, ns;

<u>Year 3 Verbal Memory with Year 3 Attainment Correlations</u>

BAS reading	$z = 0.79$, ns;
Neale reading	$z = 0.56$, ns;
Schonell spelling	$z = 0.85$, ns.

<u>Year 2 Visual Memory with Year 2 Attainment Correlations</u>

BAS reading	$z = 1.50$, ns;
Neale reading	$z = 1.54$, ns;
Schonell spelling	$z = 0.44$, ns.

<u>Year 2 Visual Memory with Year 3 Attainment Correlations</u>

BAS reading	$z = 0.49$, ns;
Neale reading	$z = 0.62$, ns;
Schonell spelling	$z = 0.01$, ns.

<u>Year 3 Visual Memory with Year 3 Attainment Correlations</u>

BAS reading	$z = 0.43$, ns;
Neale reading	$z = 0.31$, ns;
Schonell spelling	$z = 1.28$, ns.

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Orthographic Analogies and Phonological Awareness: Their Role and Significance in Early Reading Development

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Abstract—Two studies investigated young children's use of analogies in reading. In Study 1, 6-year-old children were trained to criterion on a series of clue words. Following training, they read more words that shared spelling patterns with the clue words than control words. However, this effect was reduced when the clue word was not exposed at post-test. Study 2 showed that there was a significant relationship between rhyming and analogising at age 6, but the predictive relationship between phonological skills at ages 4 and 5 and use of analogy at age 6 was not significant.

Keywords: Analogy, phonological awareness, reading

Stage models of reading, such as those of Marsh, Friedman, Welch and Desberg (1980), Frith (1985) and Ehri (1987), have typically described the earliest stage of reading development as one in which children take note of partial visual features of a word or in which they rely heavily on context-based guessing. According to such models, once children have acquired knowledge of sound to letter relationships, they emerge into the alphabetic or phonetic stage characterised by their ability to apply sequential grapheme to phoneme correspondence rules. In the final orthographic or morphemic stage, children apply higher-order rules together with their knowledge of the pronunciations of complex orthographic sequences to enable them to develop a sophisticated reading vocabulary.

Most stage models can be aligned with the traditional dual route model of reading in which there are two possible ways of reading a given word (Coltheart, 1978). One way is *direct access* in which the letter indentifies of a printed word are used to access its orthographic representation in the mental lexicon; this route applies to the reading of familiar words. The alternative strategy is by *indirect access* in which the letter identities of a printed word are first segmented into graphemes, after which a phonological representation is assembled by applying grapheme to phoneme correspondence rules; this strategy can be applied to the reading of regular words and nonwords.

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More recently, a third possible mechanism for reading, that of *analogy,* has been described (e.g. Glushko, 1979). When reading by analogy, readers synthesise the pronunciations of new words based on their knowledge of known words with similar spelling patterns. This mechanism may be very important in learning to read. Thus, a child who knows how to read the word "beat" can, through the process of analogy, infer the pronunciation of similarly spelled words like "meat, heat". Marsh *et al.* (1980) proposed that analogical processes could be used by readers in the final stage of reading development. However, in a series of elegant experiments, Goswami has challenged this view that analogies can only be used by older children and adults (see Goswami & Bryant, 1992, for a review).

Goswami (1986) presented 5–6-year-old children with a clue word e.g. "beak", and then asked them to read other words, some of which were analogues of the clue word e.g. "peak, weak", while others were control words which could not be read by analogy but were equally visually similar in that they shared three letters e.g. "lake, pake". Goswami found that the beginning readers read correctly more analogy than control words. Moreover, young children made more analogies in reading when the shared letter sequence was at the end of the word than at the beginning; more analogies were made between "beak" and "peak" than between "beak" and "bean". Goswami (1991) extended this work to show that children find it easier to make analogies when the onset–rime distinction within a word is preserved. The onset of a word is its initial consonant or consonant cluster, while the rime is the vowel and following consonants. Goswami compared children's use of analogies when reading new words with either shared consonant clusters at the beginning such as *tr*im, *tr*ap (where the cluster corresponds to the complete onset), or at the end as in wi*nk*, ta*nk* (where the cluster is part of the rime). The children made more analogies for the beginning than the end clusters because the former preserved the onset–rime boundary.

In the majority of Goswami's experiments, children trained on the clue words were allowed to refer back to them during the analogy post-test phase. Indeed, they were encouraged to do so. An exception to this was one experiment in which 24 6–7-year-old children were trained on a pair of analogy words to a criterion of two consecutive correct responses (Goswami, 1988, Experiment 2). The training made explicit reference to the common spelling sequences in the analogy words, and encouraged the use of an onset–rime breakdown. An analogy effect was obtained without the clue word being exposed at post-test. However, a more powerful case could be argued for children's early use of analogy if it could be demonstrated that they can apply the analogy principle without having to be prompted to do so, or needing to have their attention drawn to onset–rime units in words. In short, we need to be cautious before accepting that beginning readers have access to analogy as a strategy for reading which they employ naturalistically.

According to Goswami (1986), the majority of 5-year-olds who were able to make analogies successfully could read none of the words in a standardised reading test. Thus, children's ability to make use of analogy did not appear to be dependent on existing reading skill. Ehri and Robbins (1992) came to a different conclusion, however. They classified 6-year-old children into decoder and nondecoder groups. The classification was made on the basis of performance on a consonant–vowel–consonant (CVC) nonword reading test, also taking account of the children's performance on a test of letter naming and a standardised reading test. Ehri and Robbins found that children with established phonic decoding skills were able to read analogy words after being trained to criterion on a series of clue words. In contrast, the nondecoders did not learn to read the analogy words any more easily than the control words during the practice trials. Rather, these "novices" tended to read words by remembering partial letter sound cues in the words, usually the first and final letters, and as a consequence they frequently misread analogy words as training (clue) words. Arguably, the measure of phonic decoding that Ehri and Robbins used may itself have been an analogy measure since some of the simple CVC nonwords could be read by analogy. However, their results do suggest that very early readers may not be able to use analogies effectively. In short, incomplete lexical knowledge that does not contain sufficient letter detail to identify rime units will not favour reading by analogy.

Similar conclusions were drawn by Bruck and Treiman (1992). In their study, groups of 6-year-old children were allocated to one of three differing analogy training conditions: a rime training group, a consonant–vowel training group, and a vowel training group. The children in the rime training group were required to read target words that shared the rime of the clue word e.g. "pig" and "big"; the children in the consonant-vowel training group read target words that shared the initial consonant and vowel of each clue word e.g. "pig" and "pin"; and the children in the vowel training group read target words that shared the vowel but none of the consonants of each clue word e.g. "pig" and "bit". The results suggested that learning to pronounce words on the basis of rimes worked well at first; the rime training group required fewer trials to meet criterion than either the consonant–vowel or vowel training groups. However, it was the children in the vowel training group who achieved the best long-term result, both in remembering the real words they had been taught, and in generalising the training to nonwords. Bruck and Treiman concluded that children need instruction not just in the relations between groups of graphemes and groups of phonemes but also between single graphemes and single phonemes. However, it is possible that the poorer retention and generalisation of the rime training group was explained by the fact that, because they took fewer trials to reach criterion in the training stage, they had less practice and experience of the words than did the other groups.

Finally, Goswami (1990) has hypothesised that there is a causal link between early rhyming ability and children's subsequent use of analogy in reading. She found that children's rhyme awareness, as measured by the Bradley Test of Auditory Organisation (Bradley, 1980), was more closely related to their success in making analogies than was their performance on a phoneme deletion test. Goswami and Mead (1992) have extended these findings to show that rhyme awareness is significantly associated with the ability to make end analogies (e.g. "beak—weak"), while more complex tasks of phoneme awareness, such as a final consonant deletion test, are significantly related to the making of beginning analogies (e.g. "beak—bean"). The authors concluded that rhyme awareness reflects an awareness of onset–rime boundaries within words, while final consonant deletion tasks, that break up the rime unit, tap the more advanced skill of segmenting words at boundaries other than those of onset and rime. These studies were cross-sectional and, therefore, do not speak to the predictive relationship between rhyming skill and the use of analogies. Clearly, longitudinal data, in which rhyming measures are obtained prior to the demonstration of analogy effects, are needed in order to provide evidence in support of a causal relationship between rhyming and the use of analogy in reading.

Study 1

Study 1 was designed to assess the extent to which children are dependent upon clues when using an analogy strategy in reading. The paradigm chosen was that developed by Goswami (1986). Following a pre-test, subjects were taught the pronunciation of clue words. After this came post-test trials in which the children were encouraged to read a series of words analogous with each clue, together with control words. In this experiment, half of the subjects had the relevant clue word exposed at post-test (cf. Goswami, 1986), while the other half did not.

Method

Subjects

Thirty-six children who were being studied longitudinally participated in this experiment. They had been recruited at age 4 from North London Local Authority Nurseries and had undergone extensive testing at three equidistant points in time over a two year period. The analogy experiment was carried out at the third test when the children were 6 years old and in their second year at Infants School. The children ranged in age from 5 years 9 months to 6 years 8 months, with a mean age of 6 years 3 months. Their mean IQ, based on four Verbal and four Performance subtests of the Wechsler Preschool and Primary Scale of Intelligence, WPPSI (Wechsler, 1963), was 114.67, with a standard deviation of 10.68. The children ranged in reading age from 5 years 0 months to 7 years 8 months, with a mean reading age of 6 years 2 months (British Abilities Scales Word Reading Test; Elliott, Murray & Pearson, 1983).

Design and materials

At the beginning of the experiment, the children were *pre-tested* on a list of words comprising analogy and control items. They were then *trained* to criterion on a series of clue words on which the analogy words were based. The children were randomly allocated to one of two groups at *post-test.* Half of the subjects had the relevant clue word exposed at post-test while the remaining half were tested without being able to look back at the clue word.

To exclude the possibility of obtaining word-specific effects, two sets of matched words were used (List A and List B). Half of the subjects received List A and the other half List B. In List A, the clue words were ring, back, land, told and neat. In List B, they were rang, sock, sent, mind and tail. The analogy words all contained the same rime unit as the clue, but differed in the onset (e.g. ring—*king*, mind—*kind*). The control words had three letters in common with the clue words with which they were linked, were of comparable length, but could not be read by rime analogy. The clue, analogy and control words, together with their Kucera–Francis frequencies (Kucera & Francis, 1967), are given in Table 1. All the children were taught 5 clue words and attempted to read a total of 20 analogy and 20 control words at pre- and post-test. At pre-test, the order of presentation of the 40 words was completely randomised. At post-test, the words were presented to the children in blocks of 8; the 4 analogy and the 4 control words for a given clue word were randomly interspersed. The order of presentation of the blocks was randomised across all subjects.

Procedure

All the children were *pre-tested* on the list of analogy and control words on which they would be re-tested after training. After pre-testing, the children were *trained* on 5 clue words. These were presented

Table 1. Experimental materials, including Kucera–Francis word frequencies

Clue	Analogy	Control
List A		
ring (47)	king (88)	gain (74)
	sing (34)	sign (94)
	wing (18)	rink (2)
	ping (0)	rang (21)
back (967)	pack (25)	cake (13)
	sack (8)	beak (0)
	rack (9)	bark (144)
	track (38)	crab (0)
land (217)	sand (28)	lean (20)
	grand (48)	nail (6)
	hand (431)	lend (14)
	band (53)	bald (5)
told (413)	gold (52)	doll (10)
	sold (47)	bolt (10)
	cold (171)	toad (4)
	hold (169)	lost (173)
neat (21)	meat (45)	team (83)
	heat (97)	late (179)
	beat (68)	tent (20)
	seat (54)	lane (30)
List B		
Clue	Analogy	Control
rang (21)	bang (7)	gain (74)
	hang (26)	ring (47)
	sang (29)	near (198)
	gang (22)	barn (29)
sock (4)	lock (23)	cook (17)
	dock (8)	cost (229)
	cock (5)	soak (7)
	rock (75)	sick (51)
sent (145)	dent (2)	nest (20)
	lent (5)	seen (279)
	went (507)	neat (21)
	rent (21)	step (131)
mind (325)	find (399)	mint (7)
	kind (313)	mend (2)
	bind (4)	tied (–)
	wind (63)	dine (2)
tail (24)	sail (12)	late (179)
	fail (37)	tile (16)
	mail (47)	wait (38)
	rail (16)	tail (55)

on individual flashcards, with the children told by the experimenter what each word said. The words were then shown again, this time for the child to read. If he or she was unable to read a word, the experimenter supplied the correct pronunciation. All the children were trained to a criterion of 5 words correct on three consecutive trials. There was considerable variability in the time taken to learn the clues, but as a general rule the maximum time spent training each child was 10 minutes. They were then given the analogy and control words to read at *post-test.* They were told that the words they had just learned "could help them read some of the new words". Half the children had the clue word exposed while they were shown each set of 4 analogy and 4 control words; this provided them with a visual prompt, but no reminder of the pronunciation of the word was given by the experimenter. The other half did not have the clue word exposed during this phase of the experiment. The experiment was conducted in one session lasting approximately 20 minutes for each child. The children were all familiar with the experimenters and the formal test procedures, having participated in the study over a two year period.

Results

Initial analysis of the data indicated that the effect of List was not significant ($F[1,32] = 0.05$, n.s.). The data were, therefore, collapsed across List, and the children's performance at pre- and post-test was analysed using a mixed design analysis of variance (see Table 2). There was one between subjects variable (Clue Exposure), and two within subjects variables (Word Type and Pre/Post Test).

Table 2. Mean number of words read correctly in Study 1 (maximum = 20)

		Word Type	
		Analogy words	Control words
Clue exposed	Pre-test	4.50 (5.09)	4.00 (5.32)
	Post-test	9.00 (6.68)	4.38 (5.16)
Clue not exposed	Pre-test	2.11 (3.97)	1.00 (1.80)
	Post-test	4.17 (5.47)	1.61 (2.57)

Standard deviations in parentheses.

There was a significant main effect of Word Type ($F[1,34] = 32.97$, $p < .001$), indicating that the children read more analogy than control words. The effects of Pre/Post Test ($F[1,34] = 34.08$, $p < .001$) and of Clue Exposure ($F[1,34] = 4.59$, $p < .05$) were also significant, as was the interaction between Pre/Post Test and Word Type ($F[1,34] = 24.45$, $p < .001$). There was an important 3-way interaction between Clue Exposure, Word Type and Pre/Post Test ($F[1,34] = 5.63$, $p < .05$). Tests of simple main effects indicated that the difference between the analogy and control words was greater at post-test than at pre-test ($F[1,34] = 24.45$, $p < .001$). This effect was relatively more pronounced in the group that had the clue exposed at post-test ($F[1,34] = 26.78$, $p < .001$) than in the group that did not ($F[1,34] = 4.4$, $p < .05$).

Inspection of Table 2 revealed that the children who were exposed to the clue word at post-test had higher pre-test scores on both the analogy and control words than did the children who were not exposed to the clue. To ensure that the differences between the groups at post-test could not be accounted for by differences existing at pre-test, an analysis of the post-test scores was carried out using the children's pre-test scores as covariates. Once again, there was a significant effect of Word Type ($F[1,33] = 29.32$, $p < .001$), though the effect of Clue Exposure failed to reach significance ($F[1,33] = 2.31$, $p = .138$). The important interaction between Word Type and Clue Exposure remained significant ($F[1,33] = 4.64$, $p < .05$), showing that the effect of analogy was greater when the clue word was exposed than when it was not (the adjusted means are reported in Table 3).

Table 3. Adjusted means—number of words at post-test in Study 1, taking account of differences at pre-test (maximum = 20)

	Analogy words	Control words
Clue exposed	7.47	3.04
Clue not exposed	5.70	2.97

To provide a direct measure of the size of the analogy effect, a score which described each subject's improvement between pre- and post-test on analogy words was derived. This was a difference score, calculated by subtracting the number of correct analogies made at pre-test from those made at post-test. These derived scores, which controlled for pre-test differences between the groups, were used in subsequent analyses of the analogy effect.

To test whether the children's tendency to make analogies was related to reading skill, the derived scores were correlated with concurrent reading (raw) scores on a test of single word recognition (British Abilities Scales Word Reading Test; Elliott *et al.*, 1983), and on a measure of continuous (prose) reading (Neale Analysis of Reading Ability—Revised; Neale, 1989). The correlations were carried out separately for the children in the two exposure conditions. For the children who had the clue exposed at post-test, neither the BAS nor the Neale reading scores correlated significantly with the derived scores (.25 and .16, respectively). However, for the children who did not have the clue exposed at post-test, the Neale reading scores significantly correlated with the derived scores ($r = .42$, d.f. = 17, $p < .05$). The correlation between the derived scores and performance on the BAS reading test fell short of statistical significance ($r = .37$, d.f. = 17, $p = .06$). The significance of the difference between the correlations for the two groups was tested using Fisher's z transformation statistic. The differences were nonsignificant for both reading measures ($z = .37$ for BAS reading and .77 for Neale reading).

Discussion

The results of this experiment replicate and extend those of Goswami (1986, 1991), and confirm that beginning readers as young as 6 years can use analogies when reading new words. Thus, analogy words were read more easily than control words following training with clue words on which the analogy words were based. Since different word lists produced no discernible effect on our subjects' ability to apply analogy principles, it would seem that children are not unduly sensitive to certain orthographic sequences above others.

A second question which this study addressed was the extent to which beginning readers use analogy spontaneously, that is, in the present context, when the clue word was not exposed at post-test. We found that when the clue word was removed at post-test, the size of the analogy effect, though still significant, was substantially smaller than when the clue word was present. This was true even when differences in performance on the words at pre-test were controlled. Our findings suggest that children analogise more effectively if they have the opportunity to refer back to the clue word. It might be that the visual similarity between the clue word and the new word alerts the child to the use of analogy. Alternatively, the clue word might remind the child of the pronunciation of the rime segment. This experiment does not allow us to distinguish between these possibilites. However, it does lead us to doubt that young children spontaneously use analogies with any degree of frequency. The extent to which they will do so depends upon their reading level. We would therefore propose that while young readers have the potential to use analogies, this strategy will only come into force after they have had the opportunity to develop a sight vocabulary on which to base their analogical inferences.

This experiment did not formally attempt to address the issue of whether analogy skills are detectable in children with few, if any, reading skills. However, we found that analogising correlated with a measure of reading in the children who were not exposed to the clue prompt at post-test. Thus, a measurable degree of reading skill may be necessary for analogising when it is not possible to refer to a clue. In the absence of clue words, children need to draw on other reading skills to aid word identification. For instance, they may use what limited phonic decoding skills they have to decode the initial part of the word and then use some of the letter cues in the final part to generate plausible candidate pronunciations. Any of these that match phonologically with pre-existing words in the child's spoken vocabulary might be tendered as acceptable responses. It is also of interest that of the 36 children in this study, 10 obtained 0 scores for all the words at both pre- and post-test, i.e. no analogy effect was evident. All 10 were amongst the poorest readers and spellers in the sample, and 3 were effectively nonreaders. On the other hand, all the children demonstrating the analogy effect had at least some reading and spelling skills; they registered scores which were above floor level on the BAS and Neale tests at the time of the experiment. Thus, the present findings concur with those of Ehri and Robbins (1992) and of Bruck and Treiman (1992) who claimed that children need some decoding skill at the level of grapheme to phoneme correspondence to be sufficiently analytic about spellings to read words by analogy. Our results are at odds with Goswami's claim that analogy effects are demonstrable in nonreaders. It would seem that a rudimentary reading vocabulary, and very possibly basic phonic decoding skills, need to be present before children can read by analogy, especially in the absence of a specific prompt.

Study 2

Goswami (1990) and Goswami and Mead (1992) have proposed that children's successful use of analogy is dependent on their pre-existing rhyming skills. In

Goswami's (1990) study, children's performance on the Bradley Test of Auditory Organisation (Bradley, 1980) and a test of phoneme deletion (adapted from Content, Morais, Alegria & Bertelsen, 1982) was related to their use of analogy in reading. When rhyming scores were entered, after scores on a test of receptive vocabulary (British Picture Vocabulary Scale, Dunn, Dunn & Whetton, 1982) in a two step multiple regression, they accounted for 28% of the variance in analogising. Rhyming still accounted for 20% of the variance after controlling for the effects of phoneme deletion. Goswami has thus argued for a special link between rhyming ability and analogising. Further to this, Goswami and Bryant (1990) have hypothesised that rhyming skills promote children's awareness of the onset–rime distinction within words which may in turn influence their use of analogy in reading and spelling.

Goswami and Mead (1992) gave tests of reading, nonword reading, rhyme and alliteration (Bradley Test), syllable segmentation, deletion of initial or final consonants and complete phoneme segmentation to 44 6 year olds. These skills were related to the children's ability to read beginning and end analogies. More analogy than control words were read correctly, and end analogies proved easier than beginning analogies. A series of fixed order three-step multiple regressions was carried out, relating the phonological variables to analogy, after controlling for the effects of reading ability and nonsense word reading. The rhyming measures significantly contributed to end analogising, while the ability to delete final consonants significantly related to beginning analogies. The ability to rhyme and to make end analogies was taken to reflect the children's awareness of onset–rime distinctions within words, whereas the ability to delete a final consonant and to make beginning analogies demanded the segmenting of words at boundaries other than those of onset and rime.

Our second study reports results from a longitudinal study of children's reading development. The focus of the present investigation was on the children's phonological awareness before and during the beginning stages of learning to read, and its relation to their later use of analogy in reading. The tests used in this study were chosen to tap a wide range of phonological skills. We decided not to use the Bradley test as our rhyming measure because it has been criticised as taxing young children's memory resources (Wagner & Torgesen, 1987). Instead, we used a test of rhyme detection which employed pictures, together with a test of rhyme production and three further tests of phoneme awareness. Our study provided an opportunity to directly test Goswami's hypothesis that rhyming skills causally influence children's development of analogical processes in reading.

Method

The 36 children who participated in the analogy experiment (Study 1) made up the sample for Study 2.

Design and materials

The following tests of phonological awareness were administered:

(1) *Rhyme detection.* The rhyme detection test was presented in picture format, with three demonstration items followed by 10 test items. The children were required to indicate which of three words (e.g. fish, gun, hat) rhymed with or "sounded like" the target word (e.g. cat). All words were accompanied by a representational drawing. The instructions were given as follows: "Here is a picture of a cat. Which

of these three, fish, gun or hat (the child named them out loud) rhymes with or sounds like cat?" The test was scored for number of correct rhyming responses out of 10.

(2) *Rhyme production.* In this test, the children were given 30 seconds to produce words which rhymed with each of two target words (day, bell), both real and nonwords being permissible responses. The score was the number of rhyming words produced by the child during the time limit.

(3) *Phoneme identification.* This test was based on a task devised by Morag Stuart (Stuart & Coltheart, 1988). The child was shown a series of pictures of common objects, each having a single syllable word name. The examiner supplied the first two phonemes of the word which the child was requested to "finish off". There were eight items that required the child to supply the end phoneme of the word, e.g. "this is a picture of a ca-" for which the correct response was "t" to complete the word "cat". Each item was scored 1 or 0.

(4) *Phenome deletion.* This test was based on a task originally described by Bruce (1964). The child was shown a picture of a common object, e.g. a bus, and then requested to say its name after deleting the initial phoneme, always a single consonant onset, e.g. "bus" without the 'b' says . . .". The correct response was "us", also a word in its own right and crediting a score of 1. Four demonstration items were given followed by 10 test items.

All the words used for the above rhyming and phonological awareness tests were selected from Bridie Raban's corpus of spoken vocabulary in 5-year-old British children, and had a minimum frequency rating of 5 (Raban, 1988).

(5) *Sound blending.* In this task from the Illinois Test of Psycholinguistic Ability, ITPA, (Kirk, McCarthy & Kirk, 1968) the examiner supplied the constituent phonemes of single syllable words, multisyllabic words and nonwords. The child was asked to "join them together to make the word", e.g. "c – a – t" blends to yield "cat".

The children's scores on these five tests were used as predictors in a set of multiple regression analyses, with performance in the analogy test, i.e. the size of the analogy effect as the dependent variable.

(6) *Standard tests of reading.* These were the British Abilities Scales Word Reading Test, BAS (Elliott, *et al.*, 1983), a test of single word reading, and the Neale Analysis of Reading Ability—Revised (Neale, 1989), a test of prose reading.

Procedure

The first four tests described above were given to the subjects when they were 4, 5 and 6 years of age. The test sessions were separated by exactly one year. The test of sound blending and the standardised reading tests were given only at the 5 and 6 year test sessions.

Results

Table 4 shows the performance of the children on the tests of phonological awareness at ages 4, 5 and 6, together with their performance on the reading tests at ages 5 and 6. A clear cut developmental progression was evident for all measures. In Year 1, the phoneme identification and deletion tests were noted to be especially difficult, an observation which is in accord with the literature on the development of phonological awareness (Adams, 1990). In Year 2, the children had only limited literacy skills. By Year 3, the scores on all the measures were higher, though on none of them were the children at ceiling.

To examine the relationship between the children's phonological awareness and their developing literacy skills, simple correlations were carried out. Before carrying out these analyses, the distributions of the scores on the phonological awareness and reading tests were assessed using histogram analysis (with normal curve superimposed). There was a tendency for some phonological tests to be at floor at age 4 (phoneme

Table 4. Performance on the tests of phonological awareness and reading at ages 4, 5 and 6 (means and standard deviations)

Test	Age 4	Age 5	Age 6
Phonological tests			
(raw scores, maximum in parentheses)			
Rhyme detection (10)	5.5 (2.9)	8.1 (2.4)	8.4 (2.6)
Rhyme production*	1.1 (1.7)	2.8 (3.2)	5.2 (4.4)
Phoneme identification (8)	2.1 (2.5)	3.4 (3.2)	6.4 (2.6)
Phoneme deletion (10)	0.4 (1.5)	2.4 (3.8)	5.2 (4.4)
Sound blending (32)		14.0 (5.5)	18.4 (5.9)
Reading tests			
(number of words read correctly)			
BAS reading	0	3.8 (5.6)	17.2 (15.1)
Neale reading	0	9.2 (13.5)	57.2 (49.8)

*Number of rhyming words pronounced.

identification, rhyme production and phoneme deletion), while others began to shift in the direction of ceiling effects at ages 5 and 6 (rhyme detection). The BAS and Neale reading tests at age 5 also showed positive skew, consistent with a floor effect. Those measures with roughly normal distributions were retained for raw score analysis. The others with skewed distributions underwent the logarithmic transformations appropriate to their size and direction of skew (Tabachnick & Fidell, 1989). The scores on the phonological awareness tests at ages 4, 5 and 6 were then correlated with the children's scores on standardised measures of reading at ages 5 and 6 (Table 5).

Table 5. Correlations between phonological skills at ages 4, 5 and 6 and reading scores at ages 5 and 6

	Age 5		Age 6	
	Reading Age (BAS)	Reading Age (Neale)	Reading Age (BAS)	Reading Age (Neale)
Age 4				
IQ	.45*	.32*	.45*	.47*
Rhyme detection	.23	.19	.11	.14
Rhyme production	.07	.06	−.08	−.07
Phoneme identification	.28*	.30*	.37*	.35*
Deletion	.06	.06	.11	.04
Age 5				
Rhyme detection	.01	.02	−.02	−.02
Rhyme production	.05	.07	.18	.10
Phoneme identification	.40*	.41*	.42*	.42*
Deletion	.44*	.44*	.53*†	.57†
Blending	.37*	.29*	.48*	.48†
Age 6				
Rhyme detection			.43*	.40*
Rhyme production			.45*	.47*
Phoneme identification			.34*	.31*
Deletion			.49†	.50†
Blending			.54†	.52†

*Significant at the .05 level.
†Significant at the .001 level.

The correlations between the phonological tests at age 4 and the reading and spelling measures at ages 5 and 6 showed that only phoneme identification correlated significantly with both reading measures at ages 5 and 6.

Correlations between the phonological awareness scores at age 5 and the outcome measures in the same and the subsequent year showed that rhyming did not significantly correlate with reading at ages 5 and 6, but phoneme identification, phoneme deletion and sound blending did. Finally, concurrent correlations for the phonological awareness scores and reading and spelling at age 6 showed that all the phonological awareness measures (including rhyming) correlated with reading and spelling in the same year.

To examine whether the children's phonological awareness was related to their use of analogies, scores on each of the phonological awareness measures at ages 4, 5 and 6 were correlated with the derived scores describing the children's improvement on the analogy words from pre- to post-test. These correlations were conducted separately for the children in the clue and no clue exposure groups. The derived analogy score, which in principle ranged from 0 to 20, showed a mild positive skew and was thus subjected to the appropriate logarithmic transformation. In the group exposed to the clue at post-test, rhyme production at age 5 and rhyme detection at age 6 significantly correlated with the derived analogy scores ($r = .43$, d.f. = 17, $p < .05$; $r = .52$, d.f. = 17, $p < .05$, respectively). Phoneme deletion at age 6 also showed a significant correlation with analogy ($r = .41$, d.f. = 17, $p < .05$). None of the other phonological awareness measures correlated with analogising in this group. In the group not exposed to the clue at post-test, rhyme production at age 6 correlated very highly with analogy ability in the same year ($r = .57$, d.f. = 17, $p < .01$). No other significant correlations between phonological awareness and use of analogy were obtained for this group.

To investigate whether rhyming skills made a unique contribution to analogising, a series of fixed order multiple regression analyses was carried out. Transformed variables were used where appropriate. Although the ratio of subjects to independent variables meets the minimum requirement recommended by Tabachnick and Fidell (1989), it is not as favourable as it might be. The regression results are consequently interpreted with some caution.

Since Verbal IQ and Neale reading had been found to significantly correlate with analogising for the no clue exposure group ($r = .52$, d.f. = 17, $p < .05$; $r = .42$, d.f. = 17, $p < .05$, respectively), it was important to enter these likely contributors to analogising ahead of the phonological tests in the first set of regressions. Thus, clue exposure type was entered as the first step, followed by Verbal IQ, then by Neale reading, and finally by each of the phonological awareness tests given at age 6 separately. Since rhyme production at age 5 had shown a significant correlation with analogising in the group exposed to the clue at post-test, this measure was also included in the multiple regressions.

The results of this analysis showed that clue exposure type significantly contributed to the variance in the use of analogy. However, neither Verbal IQ nor Neale reading made an independent contribution to analogising once clue exposure type had been accounted for. None of the phonological awareness measures significantly contributed to the use of analogy when entered as the last step in these analyses.

The second multiple regression analysis was carried out following the steps employed by Goswami (1990). In this analysis, clue exposure type was entered first, followed by Verbal IQ, then by each of the phonological tests (Table 6).

Table 6. Three step multiple regressions relating analogies to phonological variables at ages 5 and 6 (dependent variable—derived analogy score)

	Change in R^2	F	p
Step 1 (same for all)			
Clue exposure type	16.4	6.7	.05
Step 2 (same for all)			
Verbal IQ	4.4	4.3	ns
Step 3			
Rhyme detection	5.4	3.8	ns
Rhyme production	9.7	4.7	.05
Phoneme identification	1.0	2.8	ns
Phoneme deletion	4.4	3.6	ns
Sound blending	0	2.8	ns
Rhyme production (at age 5)	0	2.9	ns

Once again, clue exposure made a significant contribution to the use of analogy. Once this had been accounted for, Verbal IQ did not emerge as a significant contributor. However, in this analysis, concurrent rhyme production made a significant and independent contribution to analogising when entered as the final step, though performance on the other phonological measures did not.

Since neither Verbal IQ nor Neale reading accounted for a significant amount of variance in analogising, a two step multiple regression was justified, entering clue exposure type ahead of each of the phonological measures (Table 7). In these analyses, clue exposure, concurrent rhyme detection and rhyme production emerged as significant.

Table 7. Two step multiple regressions relating analogies to phonological variables at ages 5 and 6 (dependent variable—derived analogy score)

	Change in R^2	F	p
Step 1 (same for all)			
Clue exposure type	16.4	6.7	.05
Step 2			
Rhyme detection	9.7	5.8	.05
Rhyme production	14.1	7.2	.05
Phoneme identification	0.1	3.4	ns
Phoneme deletion	8.0	5.4	ns
Sound blending	1.2	3.5	ns
Rhyme production (at age 5)	2.0	3.8	ns

Finally, the original multiple regression analyses were repeated separately for the two clue exposure type groups. Verbal IQ was entered first, followed by reading scores, and finally by each of the phonological tests which had shown a significant correlation with analogising. For the clue exposure group, the BAS reading score was used in preference to the Neale because of its higher correlation with analogising in this group. Neither Verbal IQ nor BAS reading ability made a significant contribution to analogising ($F[1,16] = .12$, and $F[2,15] = .99$, respectively). Rhyme production at age 5 did not account for a significant amount of variance when entered as the last step in the multiple regression ($F[3,14] = 1.85$). However, rhyme detection at age 6 significantly contributed to analogising in this group ($F[3,14] = 2.87, p < .05$). None of the other phonological tests made a significant contribution. For the group not exposed to the clue at post-test, neither Verbal IQ nor Neale reading ability accounted for a significant amount of variance in the derived analogy scores ($F[1,16] = 1.97$ and $F[2,15] = 1.04$, respectively). Of the phonological tests, only rhyme production at age 6 made a significant contribution to the analogy effect when entered as the final step after Verbal IQ and Neale reading ($F[3,14] = 2.51, p < .05$).

In all of the multiple regression analyses, most of the variance was accounted for by clue exposure type (some 16% of the variance in analogising). In contrast, Verbal IQ accounted for only 4.4% of the variance, and Neale reading ability for only 2.6% of the variance in the three and four step analyses. Of relevance to the "rhyme as a special link hypothesis", rhyme production accounted for a significant 14% of the variance after controlling for clue exposure type in the two step analysis (and a still significant 9.7% in the three step analysis). For the group not exposed to the clue at post-test, concurrent rhyme production contributed a significant 22% of the variance in analogising after controlling for Verbal IQ and reading skill, and for the group exposed to the clue at post-test, concurrent rhyme detection accounted for a significant 26% of the variance.

Discussion

The present study has confirmed the findings of Goswami (1990) and Goswami and Mead (1992) in demonstrating a special link between rhyming and children's use of analogy. Simple correlations showed that rhyme production at age 5, together with rhyme detection and phoneme deletion at age 6, correlated significantly with analogising in the group exposed to the clue word at post-test. Concurrent rhyme production correlated with the analogy effect in the group not exposed to the clue at post-test. The phoneme deletion task employed in this study required the children to split the word into its onset and rime, and then to delete the onset. It could, therefore, be viewed as a test of onset-rime awareness. Its correlation with the analogy effect might be explained by this fact. Goswami (1990) described a near significant contribution of initial consonant deletion to analogy in her three-step multiple regression ($p = .07$). Also, Goswami and Mead (1992) found that initial consonant deletion made a significant contribution to end analogising after controlling for reading ability.

In the multiple regression analyses, a large proportion of the variance was attributable to whether or not the clue was exposed at post-test. However, when the effect of clue exposure was controlled, concurrent rhyme production made a significant contribution to analogising in both the two and three step multiple regressions.

These analyses provide evidence confirming the important role of rhyming in the development of analogical processes in reading. However, the strong causal connection, hypothesised by Goswami (1990) and Goswami and Mead (1992), is not borne out by the present findings. Rhyming skills measured at ages 4 and 5 did not significantly contribute to analogising at age 6. Rather, it was rhyming ability in the same year which seemed to be the most important factor.

General Discussion

The results of these experiments have replicated Goswami's finding that very young children can use analogies in reading. Study 1 confirmed that children as young as 6, receiving training on clue words, were able to transfer this knowledge to new words having rimes analogous to words on which they were trained. However, we found that the analogy effect was substantially reduced when the children did not have access to the clue word during the post-test phase. We would conclude that Goswami underestimated the role of the clue word as a referent during the post-test. Without this reminder of the orthographic structure of the clue word, children are less able to transfer knowledge of the pronunciation of the shared letter sequence to new words.

We found that the analogy effect correlated significantly with reading performance for the children who were not exposed to the clue at post-test. However, the difference in correlations between the two clue exposure groups did not attain significance, a not surprising finding in view of the small sample size. While recognising that these results need to be replicated in a larger scale study, we would propose the following tentative explanation. For the children not exposed to the clue at post-test, training on the clue word may have primed their pre-existing lexical knowledge of words that were orthographically similar. Such knowledge would have been more easily retrieved during reading at post-test. However, for the children who had the clue exposed at post-test, the influence of pre-existing lexical knowledge would have assumed far less importance, since they always had the clue available for reference.

The analogy experiment took place in the final year of a longitudinal study that investigated the influence of phonological awareness and letter knowledge on the development of early literacy skills (Muter, in preparation). Principal components analyses conducted on the phonological awareness measures in each year of the study revealed two consistently emerging factors. The tests of rhyme detection and rhyme production loaded strongly on a *rhyming* factor, while the tests of sound blending, phoneme identification and phoneme deletion loaded strongly on a *segmentation* factor. In a series of path analyses, these two factors were found to exert differential influences over early reading and spelling development. Segmentation ability, in interaction with letter knowledge, fuelled progress in reading, and in particular spelling, during the first year at school. Rhyming did not contribute to reading or spelling performance in the first year, but did have a significant influence, alongside segmentation, on spelling progress in the following year. In contrast, neither segmentation nor rhyming skills contributed to reading ability in the second year; the major contributors were in fact reading vocabulary from the previous year, together with concurrent letter knowledge. Taken together with the present results, these findings favour an interpretation of children, first using knowledge of sound-to-letter relationships to read and later, with increasing awareness of orthographic regularities and rhyme, using analogies. Spelling, on the other hand, remains phonological, with both segmentation and rhyming exerting a significant influence over its development.

Thus, both the present analogy experiment and the broader longitudinal study, within which it was embedded, offer only partial support for the model proposed by Goswami and Bryant (1990). Goswami and Bryant hypothesised that rhyming concentrates children's attention on onset-rime boundaries of words. Thus, awareness that "cat" can be segmented into "c-at" promotes the application of analogical principles to words that share the same rime, e.g. "cat, rat, sat mat". Later, children's phonological segmentation abilities are refined and promote their awareness of phoneme-to-grapheme relationships, enabling them to "sound out" words they are asked to read and spell e.g. "cat" is segmented into "c-a-t". In our longitudinal study, phonemic segmentation exerted the initial effect on reading and spelling during the first year of school, while rhyme, which had a special bearing on the use of analogies, did not emerge until the following year. We confirmed that rhyming in the same year was a good predictor of the skill with which children use analogies (cf. Goswami, 1990), but we found that, when children could not refer to the taught "clue" word, their use of analogies was also related to their reading skill. These results lead us to propose that children only begin to use analogies after they have started reading, and that it is at this point that rhyming skill becomes relevant. Children might use their rhyming ability to organise their lexical knowledge so that they can use it systematically when given novel words to read.

What might be the role of analogy in young children's real-life reading experiences? One possibility is that beginning readers are naturally aware of the potential of analogical inferences in reading, and so apply these spontaneously. The findings of Study 1 indicate that some children do spontaneously use analogies in their early reading experiences but the effect is relatively small, and is related to size of sight vocabulary. Our findings do nonetheless suggest that children's attention can be directed to shared letter sequence between words, and that this can form the basis of an analogy strategy. It is clear from this and previous studies that young children can be successfully trained in the use of analogical processes in reading and spelling. The implications for classroom teaching methods are clear. Instructing children in the use of analogies would take advantage of young children's awareness of the onset--rime subdivision within words (Treiman, 1985). Analogies might well be successully taught alongside the use of conventional phonic teaching methods, or be implemented shortly after children have established alphabetic sound-to-letter correspondences but before they have been introduced to more complex phonemes like digraphs and blends. Analogy, because it involves relatively large sublexical units within words, makes fewer demands on phonological processing and on auditory memory than does conventional phonemic parsing; the benefits to younger children, and those with specific reading difficulties, are obvious (Wise, Olson & Treiman, 1990).

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