NEUROPSYCHOLOGY AND COGNITION

Developmental and Acquired Dyslexia

Neuropsychological and Neurolinguistic Perspectives

Che Kan Leong and
R. Malatesha Joshi
(Editors)

DEVELOPMENTAL AND ACQUIRED DYSLEXIA

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VOLUME 9

The purpose of the Neuropsychology and Cognition series is to bring out volumes that promote understanding in topics relating brain and behavior. It is intended for use by both clinicians and research scientists in the fields of neuropsychology, cognitive psychology, psycholinguistics, speech and hearing, as well as education. Examples of topics to be covered in the series would relate to memory, language acquisition and breakdown, reading, attention, developing and aging brain. By addressing the theoretical, empirical, and applied aspects of brain-behavior relationships, this series will try to present the information in the fields of neuropsychology and cognition in a coherent manner.

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DEVELOPMENTAL AND ACQUIRED DYSLEXIA

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PREFACE

It was during a pleasant and warm (both literally and figuratively) two-week period in October, 1991 that a number of researchers, scholars and clinicians from diverse lands gathered at the beautiful Château de Bonas, near Toulouse, France to discuss psychological, neuropsychological and neurolinguistic aspects of reading and writing disorders. The occasion for the serious disputations of theories, research findings and clinical applications was the Advanced Study Institute (ASI) under the auspices of the Scientific Affairs Division of the North Atlantic Treaty Organization (NATO). There was much sharing of mutual experiences, and considerable debate on some issues. There were also friendly exchanges, 'international' ping-pong, tennis matches, and bicycle races, and even some conviviality akin to that of a class reunion with members telling their stories of yesterday and visions of tomorrow.

All these serious scientific disputations and the friendly exchanges would not have been possible without the major assistance from NATO and other institutions and individuals. We wish to express our deep appreciation to Dr. L.V. da Cunha of NATO Scientific Affairs Division, Dr. Tilo Kester and Mrs. Barbara Kester of the International Transfer of Science and Technology (ITST) for their active support and substantial assistance throughout the Advanced Study Institute; Mr. Charles Stockman and his staff of the Château de Bonas for looking after our stay there; Christi Martin and Xi-Wu Feng of Oklahoma State University, and the University of Saskatchewan generally for facilitating our work.

In particular, we are grateful to our authors for their papers and all ASI participants for their contribution to the discussion. Many of the chapters were modified or rewritten some months after the Advanced Study Institute and were refereed and edited with regard to substance and integration across disciplinary boundaries. Because of the considerable number of papers and the multi-disciplinary and multi-faceted nature of the Institute, we have divided all the accepted papers into two volumes. The companion volume *Reading Disabilities: Diagnosis and Component Processes* co-edited by Joshi and Leong was published by Kluwer Academic Publishers as the NATO ASI Series Volume 74 in the latter part of 1993. The eighteen chapters in that volume with contributors from North America, England and Europe, Scandinavia, Australia and New Zealand are divided into three parts. Part 1 focuses on differential diagnosis of reading disabilities;

Part 2 on language-related component processes, especially phonological processing; and Part 3 centers around reading and spelling strategies.

The present volume contains the three related parts on developmental and acquired dyslexia: Part 1 deals with neuropsychological substrates; Part 2, case studies; and Part 3, computational and linguistic approaches. As with the companion volume, our authors are from England and Wales, different parts of Europe, Scandinavia, North America, and Russia. The two volumes would be enhanced with contributions from the following scholars, were they able to furnish us with their chapters: Professors Paul Bertelson, Alfonso Caramazza, Linnea Ehri and Richard Olson. We were, however, happy to have listened to their invited lectures and interacted with them during the Institute.

In the companion volume, we exhort our readers to "read, mark, learn, and inwardly digest" the multi-faceted topic of diagnosis and component processes of reading disorders. For this volume on developmental and acquired dyslexia, we are reminded of what Socrates wrote in *Meno*: ". . . If we believe that we must try to find out what is not known, we should be better and braver and less idle than if we believed that what we do not know is impossible to find out and that we need not even try."

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PART 1

NEUROPSYCHOLOGICAL SUBSTRATES

CHE KAN LEONG AND R. MALATESHA JOSHI

EDITORS' COMMENTS

In a volume on the appraisal of knowledge on dyslexia to the late 1970s, one of the authors defined [developmental] dyslexia as a "diagnosis of atypical reading development" as compared with other children of similar age, intelligence, instructional program, socio-cultural status and "is due to a well-defined defect in any one of the specific higher cortical functions" (Mattis, 1978, p. 54). In the intervening fifteen years, there have been advances and refinements.

Theory-based empirical studies and clinical observations have shown phonological processing deficiencies to be at the core of developmental dyslexics' 'atypical reading development' with some such children also showing orthographic processing difficulties (see Joshi and Leong, 1993, for representative views). The locus of the structure implicated in 'higher cortical functions' is also more clearly delineated as a result of advances in theory, research and practice reinforced by technology. Sherrington's (1940) vision of large-scale visualization of physiological activities is realized with the advent of neuroimaging techniques. Noninvasive neuroimaging technology, particularly magnetic resonance imaging (MRI) with its high anatomic resolution, permits *in vivo* search for subtle and mild changes in 'geometric configurations' of the human brain; and adds to our understanding of the biological bases of dyslexia and other language and learning disorders (Filipek and Kennedy, 1991). From a neuropsychological perspective, Cohen *et al.* (1993) provide a clear account of functional magnetic resonance imaging (fMRI) to measure hemodynamic responses in the brain during the performance of cognitive and linguistic tasks; and advocate converging methodologies to accommodate the strengths, potentials and areas of weakness of complementary neuroimaging techniques.

In his research program on brain morphology and dyslexia, **Hynd** and his colleagues have identified from magnetic resonance imaging subtle or mild abnormalities and only rare lesions in developmental dyslexia (Hynd and Semrud-Clikeman, 1989). In this volume, Hynd addresses relevant issues of neuroimaging studies of reversed asymmetry (from the expected left longer than right) in the posterior temporal region including the planum temporale, as compared with cytoarchitectonic anomalies found by the Harvard group (Galaburda, 1989); and of neurolinguistic abilities in children with developmental dyslexia. Hynd suggests that his and other findings encourage further exploration of morphological variations in

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frontal lobes for strategic planning and 'executive' control and of thalamus regions for inter-sensory integration in developmental reading disorders within a neurolinguistic context.

There may be another intriguing possibility. Geschwind and Galaburda (1985) alluded to poorly formed callosal connections in some dyslexics. The deficient callosal function leading to inadequate or inefficient inter-hemispheric transfer of information across the corpus callosum was also a possible 'speculation' (Hiscock and Kinsbourne, 1987) to account for anomalous hemispheric specialization and reading disorders.

The notion of bilateral frontal regions as possible cerebral substrates for at least some developmental dyslexics, as suggested by Hynd (this volume; Hynd and Semrud-Clikeman, 1989) and Galaburda *et al.* (1985), provides another framework for Bakker's research program on the 'balance model' (see **Bakker**; **Licht and van Onna**, this volume) to explain developmental reading disorders. In essence, Bakker's concept of linking reading strategies to cerebral processing emphasizes the different and conjoint contributions of the two hemispheres. He postulates two main types of developmental dyslexics: 'L-type' and 'P-type'. The L-type dyslexics rely unduly on lexical-semantic analyses of reading, probably because of a functional over-development of the left hemisphere; and tend to make more 'substantive' reading errors such as omissions and additions. The P-type dyslexics rely overly on right hemisphere strategies; and tend to make more 'time-consuming' reading errors such as repetitions and fragmentations. These hemispheric-specific reading strategies of the dyslexics, as tested on dichotic listening tasks, are also validated with event-related potentials (ERP) by Bakker, Licht and their colleagues in Amsterdam.

These ERP electrophysiological results also suggest possibilities of visual and auditory stimulation of the right and left hemispheres. In their condensed chapters, the Amsterdam team outlines computer training approaches with a computer program HEMSTIM for 'hemispheric specific stimulation (HSS)' via the visual halffields. Perhaps from a different route, Bakker, Licht and their colleagues may shed further light on the complementary bihemispheric roles and possibly bifrontal involvement in reading disorders. Their neuropsychological hemispheric stimulation may with advantage incorporate some of the more cognitive and linguistic approaches such as studies using the text-to-speech (DECtalk) computer systems reported by research groups in Colorado, Guelph, Umeå and Saskatoon (see Leong, 1992, for details).

In their chapter, Licht and van Onna attempt to link P- and L-type dyslexics to the speed and quality of lexical search in word identification and the differential reaction time (RT) measures of these subtypes in aspects of lexical identification to differential resource allocation. This chronometric approach to the mental lexicon is also essentially the framework adopted by **Martos**. In his report, Martos predicates his study of the speed of visual information processing in dyslexics, compared with 'retarded' and normal readers, on the detailed foundational work of 'chronometric exploration of mind' by Posner (1978). Mental chronometry is explained by Posner (1978, p. 7) as the "study of the time course of information processing in the human nervous system", and attempts to link time course changes in cognition, language performance to physiological indicators. This is the direction of the Amsterdam work in linking chronometric techniques to evoked potential data and hemispheric functions and seems implicit in the Martos chapter. There is some hint in the latter work that the slower processing speed as a triggering mechanism of dyslexia may related to suggestive deficiencies in the transient, magnocellular subdivision of the visual pathway of dyslexics (Livingstone *et al.*, 1991).

In connection with the foundational chronometric approach, at least two issues need to be further addressed. One issue is the use of the subtractive method in treating reaction time data (also neuroimaging data), which assumed that reaction time could be partitioned into a series of additive stages and the subtraction of the time required for each stage would provide an index of the mental operation. The associated problems with this method and the need for careful task analysis were well discussed by Donders (1868/1969). The other issue is the early warning of Posner (1978) against rigid adherence to the serial-stage view of internal mental operation. He pointed out the need to take into account higher level controls ('generation'). This prescient, cautionary note is all the more appropriate with current parallel processing approaches.

Moving from children to adults, **Flowers** delineates neuropsychological profiles of a total of 81 thirty-year-old adults assessed as 'persistent reading disabled' (PRD), 'improved reading disabled' (IRD), and 'never impaired' (NI) readers based on their discrepant reading categories of childhood and adult reading scores 'given childhood reading level'. Her multivariate analyses of a number of language-related and neuropsychological tasks show that those of her subjects, defined as 'impaired' readers by adult reading measures, continue to exhibit 'residual phonemic awareness' deficits, probably because of inefficient automatic phonological processing. She further suggests differentiating between phonetic recoding in lexical access and 'phonetic manipulation' as useful in diagnosing and remediating adults with reading disorders. The need for different answers for different kinds of phonological processing are emphasized in an influential paper by Wagner and Torgesen (1987).

From a different perspective, **Castro-Caldas, Ferro, Guerreiro, Mariano, and Farrajota** provide a summary chapter of their series of studies of functional cerebral lateralization in adult illiterates in Portugal compared with school-educated readers. Central to the issue is whether the right hemisphere plays a more important role in language communication in adult illiterates. From their earlier and ongoing studies (e.g., Damasio *et al.*, 1979) and from other series of adult illiterates, the weight of evidence seems to be "less mature [left cerebral] dominance, calling for particular perceptual strategies in specific circumstances" (Damasio *et al.*, 1979, p. 337). The adult illiterates may be ambilateral with different strategies, but language is still mostly subserved in the left hemisphere. Lecours (1989) further suggests that the illiterates in the different series probably have a lower limen or threshold on the left side and would need to use right hemisphere strategies to access tasks that literates can do using mainly left hemisphere functions. Thus from another route, we are reminded of the complementary and conjoint contributions of the two hemispheres.

These neuropsychological studies of adult illiterates by Castro-Caldas *et al.*, Lecours, and others also bring up some old questions. If adult illiteracy is seen as 'social alexia', does early exposure to spoken and written language, as in school-educated literates, assist in or enhance functional cerebral development? Conversely, what role do socio-cultural factors play in human brain function and cognition? All these are large issues awaiting further exploration.

At a more microstructural level, it is instructive to note the statement by Castro-Caldas *et al.* that for cognitive and linguistic behavior there is some consistency in the "biological structure that distributes in *networks* within the brain . . . in individuals matched for cultural background." The network or parallel distributed processing (PDP) approach is also seen by Hynd as integrating cognitive and neurolinguistic models to explain language and learning in dyslexics. The different chapters in Part 2 (Case Studies) and Part 3 (Computational and Linguistic Approaches) attempt to answer some of these microstructural questions.

REFERENCES

Cohen, J. D., Noll, D. C. and Schneider, W.: 1993, 'Functional magnetic resonance imaging: Overview and methods for psychological research', *Behavior Research Methods, Instruments, and Computers* **25**, 101–113.

Damasio, H., Damasio, A. R., Castro-Caldas, A. and Hamsher K. de S.: 1979, 'Reversal of ear advantage for phonetically similar words in illiterates', *Journal of Clinical Neuropsychology* **1**, 331–338.

Donders, F. C.: 1969, 'Over de snelheid van psychische processen [On the speed of mental processes], Onderzoekingen gedaan in het Psychologisch Laboratorium der Utrechtsche Hoogeschool: 1868–1869', *Acta Psychologica* **30**, 412–431. (Original work published 1868).

Filipek, P. A. and Kennedy, D. N.: 1991, 'Magnetic resonance imaging: Its role in the developmental disorders', in D. D. Duane and D. B. Gray (eds.), *The Reading Brain: The Biological Basis of Dyslexia*, York Press, Parkton, MD, pp. 113–160.

Galaburda, A. M. (ed.): 1989, *From Reading to Neurons*, The MIT Press, Cambridge, MA.

Galaburda, A. M., Sherman, G. F., Rosen, G. D., Aboitiz, F. and Geschwind, N.: 1985, 'Developmental dyslexia: Four consecutive patients with cortical anomalies', *Archives of Neurology* **18**, 222–233.

Geschwind, N. and Galaburda, A. M.: 1985, 'Cerebral lateralization. Biological mechanisms, associations, and pathology: II. A hypothesis and a program for research', *Archives of Neurology* **42**, 521–552.

Hiscock, M. and Kinsbourne, M.: 1987, 'Specialization of the cerebral hemispheres: Implications for learning', *Journal of Learning Disabilities* **20**, 130–143.

Hynd, G. W. and Semrud-Clikeman, M.: 1989, 'Dyslexia and brain morphology', *Psychological Bulletin* **106**, 447–482.

Joshi, R. M. and Leong, C. K. (eds.): 1993, *Reading Disabilities: Diagnosis and Component Processes*, Kluwer Academic Publishers, Dordrecht.

Leong, C. K. (ed.): 1992, 'Reading and spelling with text-to-speech computer systems' [Special issue], *Reading and Writing: An Interdisciplinary Journal* **4**, 95–229.

Lecours, A. R.: 1989, 'Literacy and acquired aphasia', in A. M. Galaburda (ed.), *From Reading to Neurons*, The MIT Press, Cambridge, MA, pp. 27–39.

Livingstone, M. S., Rosen, G. D., Drislane, F. W. and Galaburda, A. M.: 1991, 'Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia', *Proceedings of the National Academy of Sciences* **88**, 7943–7947.

Mattis, S.: 1978, 'Dyslexia syndromes: A working hypothesis that works', in A. L. Benton and D. Pearl (eds.), *Dyslexia: An Appraisal of Current Knowledge*, Oxford University Press, New York, pp. 43–58.

Posner, M. I.: 1978, *Chronometric Exploration of the Mind*, Lawrence Erlbaum, Hillsdale, NJ.

Sherrington, C. S.: 1940, *Man and His Nature*, Cambridge University Press, Cambridge, U.K.

Wagner, R. K. and Torgesen, J. K.: 1987, 'The nature of phonological processing and its causal role in the acquisition of reading skills', *Psychological Bulletin* **101**, 192–212.

GEORGE W. HYND

BRAIN MORPHOLOGY AND NEUROLINGUISTIC RELATIONSHIPS IN DEVELOPMENTAL DYSLEXIA

ABSTRACT. Neurolinguistic theory suggests that neurodevelopmental deviations in brain morphology may be linked to the behavioral manifestations seen clinically in children with developmental dyslexia. Neuroimaging studies using computed tomography (CT) or magnetic resonance imaging (MRI) have provided evidence that ties deviations in normal patterns of asymmetry in the posterior and central language zones to the dyslexic syndrome. While some of these findings support neurolinguistic theory, other deviations revealed through the neuroimaging and postmortem studies are not easily integrated with present neurolinguistic theory. This chapter addresses this issue and provides recommendations for future brain imaging research with children with developmental dyslexia.

BRAIN MORPHOLOGY AND NEUROLINGUISTIC RELATIONSHIPS IN DEVELOPMENTAL DYSLEXIA

The exact prevalence of developmental dyslexia is unknown but most researchers would agree that 3–6% of school-age children most likely suffer some form of reading disability (Johnson, 1986; Yule and Rutter, 1976). A number of factors seem to have an effect on prevalence estimates including geographic location (Keogh, 1986), language characteristics (Hynd and Cohen, 1983), and gender and inheritance (Smith *et al.*, 1990). Nonetheless, the number of children suffering from developmental dyslexia is such that it is reasonable to assume that at least one child in every classroom will experience significant difficulty in learning to read.

Over the past one hundred years it has been presumed that dyslexia is due to some form of central nervous system dysfunction (Hynd *et al.*, 1988). Early descriptions of children with severe reading problems note the similarity in symptoms in children with reading difficulty and those with identified brain damage (Aaron and Simurdak, 1991). However, until recently, the evidence supporting a neurological etiology in developmental dyslexia has rested on a rather infirm foundation of correlative and inferential research (Hynd *et al.*, 1991).

More recently, research efforts aimed at understanding the neurological structures implicated in developmental dyslexia have employed noninvasive neuroimaging technology; specifically, computed tomography (CT) and magnetic resonance imaging (MRI). Further, postmortem studies of

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the brains of dyslexics have been revealing in documenting the distribution of neurodevelopmental anomalies in the brains of developmental dyslexics. The results of these studies have not only provided support for the presumption of a neurological etiology in dyslexia, but have challenged our conceptualization as to which neurological regions and structures may be involved in the dyslexic syndrome.

To fully appreciate the implications of this research and the conceptual challenges it provides for future researchers, this chapter will first address the neurolinguistic model that encouraged this research. Then, a brief review of the neuroimaging and postmortem research will be provided and conclusions drawn in contrast to the predictions suggested by the previous neurolinguistic model. Finally, this chapter will conclude with a discussion of the conceptual and technological issues that need to be addressed in future research aimed at linking deficient neurolinguistic processes as found in dyslexic children to the associated deviations in brain morphology found in these children.

NEUROLINGUISTIC/NEUROBIOLOGICAL THEORY

The literature that has examined the relationship between brain morphology and neurolinguistic abilities in children with development dyslexia has evolved to a significant degree from those studies that demonstrated that natural asymmetries exist in the human brain (Campbell and Whitaker, 1986). Neurolinguistic theory provided the foundation for this research and a brief review of neurolinguistic theory is in order to place this literature in context.

Neurolinguistic Model of Reading

Research over the past several decades has documented that some dyslexic children may evidence deficits in visuo-perceptual processes (Pirozzolo, 1979), sequencing ability (Hooper and Hynd, 1985), phonemic segmentation (Liberman *et al.*, 1974), and automatized cognitive processing (Wolf *et al.*, 1986). The interactive and distributive nature of these deficits has historically been linked to what has recently been referred to as the Wernicke–Geschwind model (Mayeux and Kandel, 1985). This model has been further elaborated on by Satz (1991).

Supported by clinical lesion studies, this model implicates the involvement in reading of the bilateral posterior cortex, region of the angular gyrus at the juncture of the left parietal-temporal-occipital cortex, Wernicke's region including the superior temporal and posterior insular region, and Broca's region. In addition to the clinical lesion studies (Hynd and Cohen,

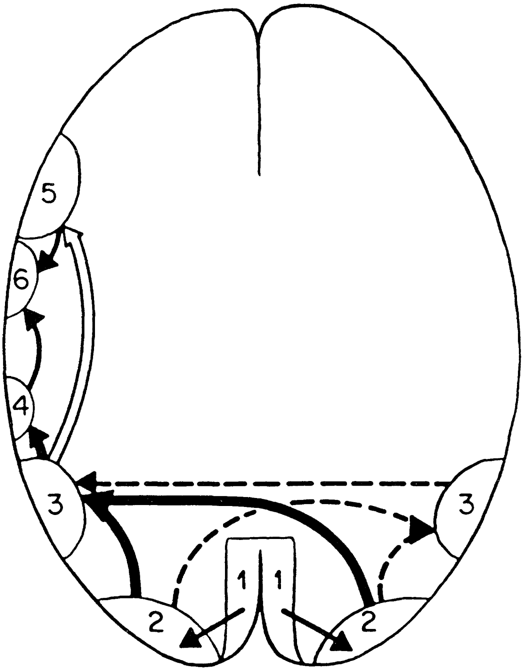

Fig. 1. Cross-section diagram of cerebral hemispheres illustrating the major pathways for reading processes. Heavy lines indicate left-hemisphere connections; lighter lines are right hemisphere connections. (1) Visual cortex, (2) visual associative cortex, (3) angular gyrus, (4) left temporal lobe language area, (5) left frontal language area, (6) left frontal lobe motor language area. [Adapted from C. H. Chase and P. Tallal: 1991, 'Cognitive models of developmental reading disorders', in J. E. Obrzut and G. W. Hynd (eds.), *Neuropsychological Foundations of Learning Disabilities: A Handbook of Issues, Methods, and Practice*, Academic Press, New York, p. 211.]

1983), topographic brain mapping of electroencephalographic activity during reading has provided some support for this model (Duffy *et al.*, 1980). As can be seen in Figure 1, this model is distributed in the left and right cerebral hemispheres and is interactive in that the visual-perceptual and auditory-linguistic cortex are significantly involved.

Many of the clinical lesion studies that have provided support for this conceptualization are derived from the adult literature on cases of acquired alexia. Despite the fact that many of these studies can be criticized on methodological grounds (Chase and Tallal, 1991), they are important because they encouraged other researchers to investigate the neurobiological basis of language.

Morphological Asymmetries in the Human Brain

The research of earlier investigators (e.g., Flechsig, 1908; Von Economy and Horn, 1930) encouraged Geschwind and Levitsky (1968) to examine natural asymmetries in the central language zones; specifically in the region of the planum temporale. They documented in 100 human brains that the region of the planum temporale is larger on the left than the right in 65% of brains while it is larger on the right in only 11% of cases. As it is known that the region of the left planum is significantly involved in language, these findings were interpreted as reflecting a natural neurobiological substrata for language. Studies by other investigators followed and provided support for the finding that this asymmetry exists in both adult and infant brains (Rubens *et al.*, 1976; Wada *et al.*, 1975; Witelson and Palli, 1973).

Other natural asymmetries clearly exist in the human brain that presumably have some relationship to higher-order cognitive processes. For example, the volume of the right frontal region exceeds that of the left in 75% of cases (Weinberger *et al.*, 1982). Also, cytoarchitectonic asymmetries seem to exist favoring some extensive development in the region of the left inferior parietal lobe (Eidelberg and Galaburda, 1984), the left auditory cortex (Galaburda *et al.*, 1978), and the posterior thalamus (Eidelberg and Galaburda, 1982). The work of Galaburda and his colleagues is very significant indeed in documenting that neurodevelopmental-cytoarchitectonic asymmetries exist.

This literature has provided the foundation for examining the relationship between brain morphology and neurolinguistic abilities. The convergence of research on the neurolinguistic basis of language and that focused on the documentation of morphological asymmetries led to a number of possible hypotheses.

Two of these possible hypotheses deserve motion in the context of this chapter.

First, there seemed to be a widely distributed neurological system primarily in the left central-posterior region that served as the foundation for fluent reading. Any disruption of this system presumably led to the often documented perceptual-linguistic deficits frequently observed in dyslexic children. Second, asymmetry favoring the left central-posterior regions was deemed as providing an appropriate neurological substrata for fluent reading. Deviations from these normal patterns may play a critical role in the clinical manifestations in dyslexia. It is exactly these hypotheses that were addressed by the neuroimaging and postmortem studies and they deserve some discussion so that directions for future research can be charted.

NEUROIMAGING STUDIES

The neuroimaging studies sought to determine if children with developmental dyslexia differed from normal children in patterns of posterior and plana asymmetry. The assumption was that if children with documented deficits in reading differed in patterns of asymmetry in the regions suggested by the neurolinguistic model, then the natural asymmetry of these regions must be important in the development of fluent reading skills and processes. As can be seen in Table 1, nine neuroimaging studies have been conducted to date to investigate this notion.

The first of these studies was reported by Hier *et al.* (1978) using CT. Employing 24 dyslexic children, they found that only 33% of the developmental dyslexics had a wider left posterior region, while 67% evidenced either symmetry or reversed asymmetry of the posterior region. Based on Geschwind and Levitsky's (1968) findings, it was concluded that symmetry or reversed asymmetry may be a risk factor for developmental dyslexia. Figure 2 for example, shows an MRI scan of a normal child (top) and that of a dyslexic child (bottom). It can be seen that the dyslexic child evidences symmetry in the posterior area whereas the normal child's MRI scan shows the typical left > right posterior asymmetry.

In an important follow-up study, Rosenberg and Hier (1980) found that a brain asymmetry index correlated with verbal-performance intelligence discrepancies such that lower verbal IQ was associated with symmetry or reversed asymmetry of the posterior region in the developmental dyslexics. Again, these findings were interpreted as supporting a neurolinguistic–neurobiological model of reading and underscored the idea that the behavioral and cognitive deficits so frequently observed in dyslexia were related in some fashion to deviations in brain ontogeny, quite possibly of congenital origin.

Further studies by Leisman and Ashkenazi (1980) and Rumsey *et al.* (1986) (using MRI) supported these conclusions. Two studies conducted during this period of time did not lend support to the notion that patterns of asymmetry differed in developmental dyslexia, however. The study by Haslam *et al.* (1981) found no differences between dyslexics and normals and Parkins *et al.* (1987) found significant differences only in left-handed men (mean age = 57 years). The failure to find significant differences in these latter two studies is difficult to integrate into a clear understanding as to why. The Haslam *et al.* (1981) study employed a less strict criteria for inclusion in the study for dyslexics than in the Hier *et al.* (1978) and Rosenberger and Hier (1980) studies, but the failure of other studies to adequately report diagnostic criteria (e.g., Leisman and Ashkenazi, 1980) clouds the possible interpretation of these negative results. Also, only the Parkins *et al.* (1987) study reported any relationship between handedness

TABLE 1
Brain imaging studies of individuals with developmental dyslexia.

Study	Type	*N*	Mean age	Diagnostic criteria	Neurological Exam	Conclusions
Hier *et al.* (1978)	CT[1]	24	25	Less than 5th-grade reading level on *Gray Oral Reading Test* or > 2 year delay in reading while in school	Normal	(1) Dyslexic subjects with reversed posterior asymmetry had lower verbal IQ (2) 33% had normal L > R posterior asymmetry; 67% had symmetry or reversed (L < R) poseterior asymmetry
LeMay (1981)	CT	27 dyslexics[2] 317 controls	NR	NR	3 dyslexics had history of seizures	(1) 33% of dyslexics had normal (L > R) posterior asymmetry compared to 70% of right-handed controls (2) Left-handed controls evidenced more symmetry and reversed (L < R) asymmetry of posterior region
Leisman and Ashkenazi (1980)	CT	8 dyslexics 2 controls	8.2 dyslexics 7.6 normals	NR	None	(1) 100% of dyslexics had symmetry or reversed asymmetry (L < R) of posterior region
Rosenberger and Hier (1980)	CT	53	6–45 (range)	Two grade levels below actual grade; large VIQ-PIQ discrepancy	11 dyslexics showed left-handedness	(1) 42% of dyslexics had reversed asymmetry (L < R) of posterior region (2) Asymmetry index correlated with verbal-performance IQ discrepancy ($r = 0.38$, $p < 0.02$)
Haslam *et al.* (1981)	CT	26 dyslexics 8 controls	11.7 dyslexics 9.8 controls	Reading performance at least 2 years below expected level based on IQ	46% of dyslexics had history of abnormal pregnancy; 50% showed soft neurological signs	(1) 46% of dyslexics showed normal (L < R) posterior asymmetry while 87% of controls did (2) No relationship between IQ and posterior symmetry or asymmetry

TABLE 1
(Continued)

Study	Type	*N*	Mean age	Diagnostic criteria	Neurological Exam	Conclusions
Rumsey *et al.* (1986)	MRI	10	22.6	Childhood history of reading disability; median *Gray Oral Reading Test* was 3.7 grade equivalent	3 subjects had soft neurological signs	(1) 90% of dyslexics showed symmetry of posterior regions
Parkins *et al.* (1987)	CT	44 dyslexics 254 controls	57	Childhood history of reading and spelling disability psychometric evidence of dyslexia	NR	(1) Concluded that reversed posterior asymmetries not characteristic of right-handed dyslexics, but left-handed dyslexics may evidence mre symmetry
Larsen *et al.* (1990)	MRI	19 dyslexics 19 normals	15.1 dyslexics 15.4 controls	Highly significant differnce between normals and dyslexics in word recognition. Selected prior to study by school as dyslexic	NR	(1) Measured the patterns of asymmetry in the region of the planum temporal. 70% of dyslexics had symmetry while only 30% of dyslexics did (2) All dyslexics with plana asymmetry demonstrated significant phonological coding deficits
Hynd *et al.* (1990)[3]	MRI	10 dyslexics 10 ADD/H[4] 10 normals	9.9 dyslexics 10. ADD/H 11.8 normals	IQ $\geq$ 85, positive family, history, reaching achievement $\geq$ 20 standard score points below full scale IQ on tests of word recognition and passage comprehension	NR	(1) Both dyslexics and ADD/H children had smaller right frontal widths (more frontal symmetry than normals) (2) 70% of normal and ADD/H children had L > R plana asymmetry while only 10% of dyslexics did. Plana symmetry of reversed asymmetry seems characteristic of dyslexics

[1] CT = computed tomography. MRI = magnetic resonance imaging. [2] LeMay (1981) used all of Hier *et al.*'s (1978) subjects adding three of her own in addition to the controls. [3] Semrud-Clikeman *et al.* (1991) employed these subjects to examine the relationship between deviations in patterns of brain morphology and neurolinguistic ability in developmental dyslexics. [4] ADD/H = Attention Deficit Disorder with Hyperactivity.

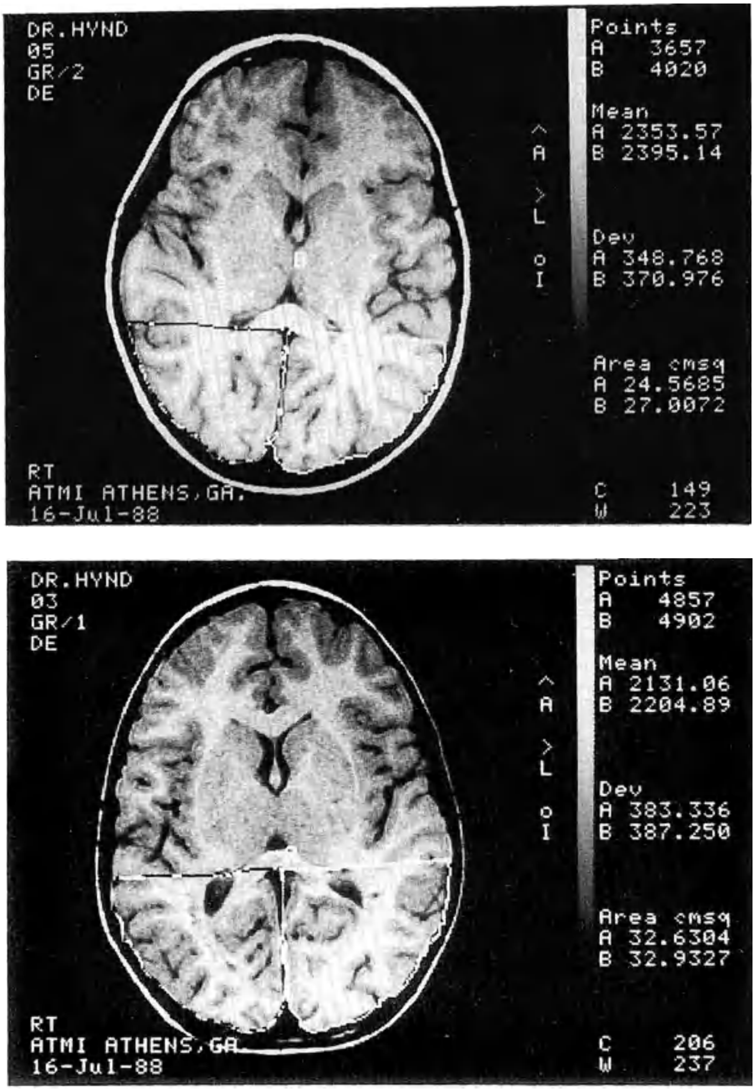

Fig. 2. MRI scan of a normal child (top) and a child with developmental dyslexia (bottom). *Note*: These MRI scans are by tradition visualized in reverse orientation such that the left side of the scan is the right side of the brain, whereas the right side of the scan is the left side of the brain. The scan of the normal child shows the typical pattern of left > right asymmetry of the posterior region (B = left side [27.0072 sq cm]; A = right side [24.5685 sq cm]). The scan of the dyslexic at the bottom shows symmetry (L = R) of the posterior region (B = left side [32.9327 sq cm]; A = right side [32.6304 sq cm]). These morphometric measurements are made directly on the MRI scan as outlined. The area in sq cm can be seen in the lower right corner of each scan. [Adapted from G. W. Hynd, R. Marshall and J. Gonzalez: 1991, 'Learning disabilities and presumed central nervous system dysfunction', *Learning Disabilities Quarterly* **14**, 283–286].

and patterns of asymmetry. While theory advanced by Geschwind and Galaburda (1985) and others would support such a finding, the absence of such a relationship in the other eight studies is striking. Consequently, those studies that examined patterns of posterior asymmetry in developmental dyslexics generally suggest that symmetry or reversed asymmetry may be associated with dyslexia.

There are indeed significant difficulties with this literature. As Hynd and Semrud-Clikeman (1989) have pointed out, the diagnostic criteria for the dyslexics were often poorly articulated, the 'control' children were frequently children whose CT scans were read as normal but had been referred for possible neurological involvement, and there were very significant differences in how asymmetry was operationalized, among other problems. Nonetheless, these studies were important in suggesting that it was worthwhile to examine patterns of asymmetry in developmental dyslexia and encouraged further studies that examined patterns of asymmetry in the region of the planum temporale in dyslexics.

Most recently, two studies have reported on the patterns of plana asymmetry in developmental dyslexia. Both of these studies employed MRI. Larsen *et al.* (1990) reported that 70% of the dyslexic children had symmetry in the region of the plana in contrast to 30% of the normals. Again, handedness was not related to the patterns of plana asymmetry. Larsen *et al.* (1990) also reported that when plana symmetry was evident that the dyslexics demonstrated phonological coding deficits. Consistent with neurolinguistic theory, they concluded that a relationship may exist between asymmetry patterns in developmental dyslexics and neurolinguistic deficits observed in many of these children.

Unique to the Hynd *et al.* (1990) study, the relative specificity of deviations in plana asymmetry in dyslexia was examined as they employed diagnosed normal control children in addition to children diagnosed as having Attention Deficit Disorder with Hyperactivity but without neurolinguistic or reading problems. As with the Larsen *et al.* (1990) study, Hynd *et al.* (1990) reported that 90% of the dyslexics had either symmetry of the plana or reversed asymmetry while only 30% of the normals and Attention Deficit Disorder with Hyperactivity children had such a pattern. This suggested that increased incidence of plana symmetry or reversed asymmetry may be unique to dyslexic children and not children with other clinical disorders of presumed neurological etiology. It should also be pointed out that both the dyslexic and Attention Deficit Disorder with Hyperactivity children differed from the normals in the width of the frontal lobes in that the normals evidenced the typical left < right asymmetry pattern (Weinberger *et al.*, 1982) while the two clinical groups evidenced symmetry or reversed asymmetry of the frontal region.

A follow-up study by Semrud-Clikeman *et al.* (1991) reported that symmetry or reversed asymmetry of the plana was associated with significant deficits in confrontational naming, automatized rapid naming, and verbal-linguistic processes. Also, symmetry or reversed asymmetry of the frontal lobes was associated with passage comprehension abilities; passage comprehension was in the normal range when there was the normal left < right asymmetry while symmetry and reversed asymmetry was associated with passage comprehension achievement one standard deviation below the mean on a standardized test. It should be pointed out that this study is not included in Table 1 since Semrud-Clikeman *et al.* (1991) employed the same subjects as in the Hynd *et al.* (1990) study.

Although dyslexics in the Hynd *et al.* (1990) and Semrud-Clikeman *et al.* (1991) studies had a higher incidence of left-handedness than the normal or clinic control children, there was no relationship to patterns of brain morphology. Thus, the increased incidence of left-handedness typically found in populations of dyslexics seems to have no relationship to patterns of brain morphology, at least as addressed by these studies.

Conclusions

What can be concluded from these studies? First, it seems that consistent with the two previously noted hypotheses there do seem to be deviations in the patterns of asymmetry in the posterior region and in the region of the plana in developmental dyslexics. Dyslexics seem to be characterized by more symmetry or reversed asymmetry in these regions. As these patterns of asymmetry presumably develop during fetal gestation and are clearly manifest by infancy (Witelson and Pallie, 1973), it would seem that something, perhaps genetic, must impact significantly during the period of neuronal migration during the third trimester of pregnancy. As will be seen, the postmortem studies address this possibility more directly.

Second, it would appear that these deviations in normal patterns of asymmetry in dyslexia may be related either directly or indirectly to the deficient neurolinguistic processes found clinically in these children. The studies by Rosenberger and Hier (1980), Larsen *et al.* (1990), and Semrud-Clikeman *et al.* (1991) all support this possibility. Consequently, neurolinguistic theory would seem to have provided an adequate foundation for pursuing neuroimaging studies aimed at articulating more clearly the neurobiological basis of developmental dyslexia.

As the discussion which follows this brief review will point out, however, there are very significant issues that need to be addressed both conceptually and technically. First, the postmortem studies deserve attention.

POSTMORTEM STUDIES

Based on the theory advanced by Geschwind and Galaburda (1985) and the neurolinguistic model noted earlier, the autopsy studies are especially valuable in providing a link between deviations in the cyroarchitecture and the dyslexic syndrome. Other than the initial study reported by Drake (1968), all of the postmortem studies have been conducted by Galaburda and his colleagues. All these studies are summarized in Table 2.

In a truly landmark study, Galaburda and Kemp (1979) reported on a developmental dyslexic who died as the result of a fall. In this particular case, the reading disability was exceptionally well documented over his educational career. The pathological findings included regions of disordered cortical layering, polymicrogyria in the region of the left planum temporale, and other focal cellular abnormalities in the brain. The importance of this initial case cannot be overstated as the results were consistent with the notion that disruptions in the cytoarchitecture in the regions known to be important to reading would characterize the brains of dyslexics (Hynd and Hynd, 1984).

Additional cases followed and all were contributed by Galaburda and his colleagues. As can be seen in Table 2, all of these cases documented focal cellular abnormalities distributed throughout the brain. In all cases the brains were characterized by symmetrical plana (Galaburda *et al.*, 1985; Humphreys *et al.*, 1990).

Hynd and Semrud-Clikeman (1989) reviewed these reports and observed that these focal cytoarchitectonic abnormalities clustered preferentially in the left frontal, left temporal, and right frontal regions. Also, the distribution and quantitative nature of these neurodevelopmental anomalies differed significantly in each case with some brains showing less involvement than others. Importantly perhaps, as was noted by Galaburda and his colleagues, there were subcortical abnormalities as well in these cases. In three of the cases abnormalities were noted in the medial-geniculate nucleus and posterior nucleus of the thalamus (Galaburda and Eidelberg, 1982; Galaburda *et al.*, 1985). As these nuclei may be related to language processes, or the allocating of sensory input, Hynd and Semrud-Clikeman (1989) hypothesized that they might relate to the deficiencies in neurolinguistic processes known to be disturbed in dyslexic children.

Conclusions

It would seem that the autopsy cases have provided evidence consistent with the basic notion that the clinical features common to dyslexia may be related to some disruption of cellular migration during the third trimester of fetal gestation. Consistent with the neuroimaging studies, symmetry

TABLE 2
Postmortem studies of the brains of developmental dyslexics.

Study	Gender	Family history	Handedness	Language delay	Cause of Death	Neuropathological findings
Drake (1968)	Male	(1) Mixed dominance (2) Learning problems (3) Migraines (4) Brother with reading problems	Right-handed	No	Cerebellar hemorrhage	(1) Abnormal gyrial pattern in bilateral parietal lobes (2) Corpus callosum thinned
Galaburda and Kemper (1979)	Male	(1) Male family members slow readers	Left-handed	Yes	Fall from building	(1) Polymicrogyria in left posterior sylvian area (2) Neurons in cell-free layer of cortex in left auditory cortex (3) Many minute cellular abnormalities throughout left hemisphere (4) Thalamic abnormality (5) Symmetrical plana
Galaburda *et al.* (1985)	Male	(1) Older brother had reading problems (2) Left-handedness (3) Allergies and migraines	Right-handed	No	Acute myocarditis	(1) Many focal dysplasias favoring left hemisphere (left temporal & left frontal) (2) Enlarged thymus (3) Thalamic abnormality (4) Symmetrical plana
	Male	(1) Younger left-handed twin brothers with reading problems	Right-handed	Yes	Car accident	(1) Many focal dysplasias (left frontal, left temporal, right frontal) (2) Old brain damage from fall at age 14 (3) Symmetrical plana
	Male	(1) Left-handedness (2) Father presumed to be mathematically gifted but possibly dyslexic	Abidexterous	Yes	Cardiac problems associated with mumps	(1) Many focal dysplasias (left frontal, right frontal, left temporal) (2) Polymicrogyria in another left temporal lobe (3) Thalamic abnormality (4) Symmetrical plana

TABLE 2
(Continued)

Study	Gender	Family history	Handedness	Language delay	Cause of Death	Neuropathological findings
Humphreys, *et al.* (1990)	Female	Not reported	Right-handed	No	Suicide	(1) Focal ectopias in bilateral frontal regions and left temporal region (2) Vascular malformation in left frontal white matter (3) Symmetrical plana
	Female	(1) One of her sons had spelling problems	Left-handed	No	Heart disease	(1) Focal ectoplas scattered throughout both cerebral hemispheres (2) Vascular malformation in left frontal region (3) Symmetrical plana
	Female	(1) Two younger brothers diagnosed as dyslexic (2) Attention deficit disorder in one brother (3) Mother had history of spelling, orientation, and writing problems	Right-handed	Yes	Complication	(1) Few focal ectoplas primarily in right hemisphere (2) Small brain tumor (3) Symmetrical plana

of the plana was a similar finding in the dyslexics. The postmortem studies are unique in that they also demonstrate that at the cellular level significant deviations occur in the bilateral frontal and left temporal regions in dyslexics. These cellular irregularities are too small to be observed through the neuroimaging procedures and thus are a unique contribution of these studies.

Again, left-handedness characterized two of the eight subjects and a third was reported to be ambidexterous. However, again there seemed to be no obvious relationship to deviations in brain morphology. It should also be noted that the three females reported by Humphreys *et al.* (1990) showed the same general pattern of cytoarchitectonic disturbance as did the other males.

Consequently, it can be concluded from these small number of postmortem studies that the brains of some dyslexics are indeed characterized by neurodevelopmental anomalies as would have been predicted by neurolinguistic theory. Many of these cellular disturbances did occur in the region of the central language zones, but a significant number also were noted in the bilateral frontal cortex as well as subcortically in the nuclei of the thalamus. It is at this juncture that we see some departure from classical neurolinguistic theory as the model of reading presented earlier does not address the possible contributions of the frontal lobes or thalamic nuclei in the functional system of reading. With these thoughts in mind, let us now consider some of these inconsistencies and ways in which future research might best address these and other issues.

THE NEED FOR NEW PERSPECTIVES IN RESEARCH

As has been noted previously, historical perspectives as to the neurodevelopmental basis of dyslexia has generally served us well in guiding the neuroimaging and postmortem studies (Hynd *et al.*, 1988). Clearly, the Wernicke–Geschwind model has highlighted those regions of the brain that are likely compromised in the attainment of fluent reading skills in dyslexics.

However, there seems to be sufficient evidence from these studies to raise questions that future research may productively examine. With regard to the neurolinguistic model presented previously in this chapter, it might well be questioned as to whether the frontal lobes are involved in the functional system of reading. Also, what role might the thalamus have in fluent reading? The neuroimaging study by Hynd *et al.* (1990) and the postmortem studies by Galaburda and his colleagues highlight the morphological variation in the patterns of asymmetry of the frontal region and the frequent occurrence of focal cellular abnormalities in the bilateral frontal lobes in dyslexics. To date, only the three postmortem studies by Galaburda *et al.* (1985) suggest thalamic abnormalities but the occurrence in three of the eight postmortem cases seems significant. These findings deserve consideration.

Frontal Lobe Involvement in Dyslexia

The clinical lesion studies of patients with acquired alexia have provided evidence that disruption to the posterior visual cortex disrupt fluent reading. The underlying notion has always been that the primary visual cortex perceives input, the secondary association cortex provides low-level feature analysis and is important in visual recognition, and that cross-modal integration with the linguistic cortex occurs in the region of the angular gyrus (Luria, 1980). The frontal lobes have long been recognized for their executive role and are known to reach adult levels of cellular maturity later than other regions of the cortex.

For example, while the decline in neuronal density in the visual cortex reaches adult levels about age five months, the decline in neuronal density in the frontal lobes are still about 10% over normal adult levels at 7 years of age. Also supporting the notion that the frontal lobes are slower to develop than other regions of the brain is the observation that synaptic density in the frontal cortex does not reach adult levels until about 16 years of age whereas it reaches adult level in the visual cortex at about age 7 years (Huttenlocher, 1990). The morphometric study of the human cortex then demonstrates a different time course of neurodevelopment for different regions with the frontal lobes having one of the longest periods of postnatal maturation.

As Hynd *et al.* (1990) and Galaburda *et al.* (1985) document, there may be significant morphological variation in the frontal regions in dyslexics and the cognitive model of reading (to be discussed below) may indeed implicate more 'executive' processes as being associated with fluent reading.

From a neurological perspective, some research supports this contention. For example, it has long been known that perseveration is often associated with frontal lesions. The difficulty frontal-lobe lesioned patients have in shifting conceptual sets is well documented (Sandson and Albert, 1984). Other research has demonstrated that frontal lesions impair spatial orientation, particularly on tasks requiring right-left discriminations (Semmes *et al.*, 1963). Also, research has demonstrated that lesions of the frontal cortex impair learning that resulted from difficulty in attending to multiple cues and in monitoring their responses such that they could differentiate between relevant and irrelevant input (Cicerone *et al.*, 1983).

These behavioral deficits sound remarkably similar to some of the clinical symptoms dyslexics demonstrate. They often have difficulty in attending to and learning from instructional material, frequently perseverate on tasks, and many descriptions exist that suggest that dyslexics have difficulty in left-right orientation (Hynd and Cohen, 1983; Hynd and Semrud-Clikeman, 1989).

Therefore, it is not unreasonable to suggest that our neurolinguistic model needs to incorporate these 'executive' like functions into the perceptual-linguistic processes known to be involved in reading. Certainly, the neuroimaging study by Hynd *et al.* (1990), the postmortem studies by Galaburda and colleagues, and the clinical lesion studies all highlight the possible involvement of the frontal lobes in reading. Their exact contribution to the process of reading acquisition will be determined only through innovative research efforts that attempt to link cognitive–executive processes and their involvement in reading to deviations in brain morphology.

The Role of the Thalamus in Language and Reading

The Wernicke–Geschwind model is primarily concerned with the cortical zones implicated in reading. Subcortical contributions to this model are not generally discussed. The thalamic abnormalities noted in three of Galaburda *et al.*'s (1985) patients involved disturbances in the medial geniculate nucleus and posterior lateral nuclei bilaterally.

The medial geniculate nucleus is involved in the central auditory system. It receives axons primarily from the ipisilateral inferior colliculus, although some cells from the inferior colliculus project contralaterally. Cells from the medial geniculate nucleus then project their axons to the homolateral primary auditory cortex in the superior temporal gyrus (Kelly, 1985a). The lateral posterior nucleus of the thalamus projects to the inferior parietal lobe. It may have a role in intersensory integration because of its projections to the region of the parietal-temporal-occipital association cortex (Kelly, 1985b) and may show a left-sided asymmetry (Eidelberg and Galaburda, 1982).

It is not unreasonable to expect that subcortical structures may be significantly involved in the functional system of reading. Certainly the thalamus is a primary candidate for consideration because of its well-documented role in language. Thalamic lesions often disrupt speech and language and may produce symptoms associated with transcortical aphasia (Alexander and LoVerme, 1980; Cappa and Vignolo, 1979). Most often these patients suffer word-finding difficulties and their expressive speech is often paraphasic containing many errors of speech.

Studies by Mateer and Ojemann (1983) and Ojemann (1975) support the idea that the thalamus is significantly involved in language. Employing electrical stimulation of the thalamus as an experimental methodology, these researchers found that stimulation of the left thalamus, not the right, elicited a slower rate of articulation, characterized by slurring and articulatory inaccuracy on naming tasks. A recent dichotic listening study conducted by Hugdahl *et al.* (1990) confirmed these findings and supported the idea that the thalamus may act as a lateralized gating mechanism for auditory-linguistic stimuli. If indeed there are neurodevelopmental anomalies in the nuclei of the thalamus in some dyslexic individuals as suggested by the Galaburda *et al.* (1985) study, then this may help explain why so many reading and learning disabled children do poorly on dichotic listening tasks (Obrzut, 1991).

Considering the frequent comorbidity between language and learning disabilities and the similarly presumed congenital nature of developmental language disabilities (Tallal *et al.*, 1989), it is a reasonable expectation that future neurolinguistic models incorporate the contribution of subcortical structures such as the thalamus.

Cognitive and Neurolinguistic Models

It is far beyond the scope of this chapter to review cognitive models of reading as they relate to the neurolinguistic processes thought to be deficient in dyslexia. However, some mention should be made that the typical methodology employed in the neuroimaging studies has not been very sophisticated in trying to unravel the relationship between deviations in brain asymmetry and deficient neurolinguistic processes in dyslexics.

With the exception of the Larsen *et al.* (1990) and Semrud-Clikeman *et al.* (1991) studies, the efforts to develop some understanding of the relationship between brain morphology and language and reading processes have been poor. Most typically, researchers document deficient reading achievement, examine brain morphology, and when differences are found, interpret the findings as supportive of the idea that asymmetry or deviations thereof are somehow related to poor reading achievement. We are again faced with inferences.

The Larsen *et al.* (1990) and Semrud-Clikeman *et al.* (1991) studies are most recent and may reflect a greater sophistication of researchers with regard to the cognitive-linguistic processes known to impact on reading achievement. As Chase and Tallal (1991) point out, a parallel distributed processing model of reading may provide a foundation for further integrating cognitive-neurolinguistic models. In this model, "processing units are neuronlike with simple excitatory and inhibitory connections; output from the system is continuous; activation is distributed and massively parallel; the system operates by constant satisfaction to settle into a solution" (p. 230).

Such a model would provide an excellent foundation for incorporating the executive functions of the frontal lobes as well as the gating mechanism hypothesized to originate from the thalamus. Further, the experimental procedures from the domain of cognitive psychology could potentially contribute significantly to our understanding of the interactions between deviations in patterns of brain morphology and neurolinguistic ability in dyslexic children. If there is one conclusion to derive from this brief discussion it is that those conducting brain morphology research could profit significantly by working with theorists and researchers in reading.

What Are We Measuring, Why Are We Measuring It, and What Should We Be Measuring?

Neurobiological theory, as advanced by Geschwind and Levitsky (1968) and others clearly highlighted the natural asymmetry of the left plana and posterior region as being vital to the evolution of language capabilities. The early CT studies, such as Hier *et al.* (1978), Rosenberger and Hier (1980), and Haslam *et al.* (1981) all focused on the importance of the posterior asymmetry in terms of developmental dyslexia. More recent studies by Hynd *et al.* (1990) and Larsen *et al.* (1990) used MRI to examine plana morphology in dyslexics. Consistent with theory, symmetry or reversed asymmetry characterized the dyslexics. Consequently, the studies conducted over the past decade and a half have in general focused on these two regions and the results have typically supported earlier predictions.

The question of what are we measuring and why are easy to answer. The question of what should we be measuring is more difficult to answer especially when one considers some technical and neuroanatomical issues. The previous review supports the idea that measuring posterior asymmetries and plana asymmetries is consistent with theoretical notions. Further, the review encourages the idea that the frontal lobes and the thalamus may be especially important to the neurolinguistic/neurobiological basis of developmental reading disorders. So, while it is easy to conclude that we may wish to examine morphological variation in other brain regions, technical and neuroanatomical considerations pose interesting possibilities.

The early CT studies employed a midaxial scan that typically best visualized the posterior temporal-parietal-occipital region. Morphometric data were collected by simply drawing a line at right angles to the longitudinal fissure half way between the occipital pole and the most posterior aspect of the corpus callosum (splenium). Right and left width measurements were thus obtained. This general methodology characterized the Hier *et al.* (1978), Haslam *et al.* (1981), and several other studies. Some studies simply used 'clinical judgement' to derive an indication of asymmetry (e.g., Leisman and Ashkenazi, 1980; Rumsey *et al.*, 1986). As might be suspected, reliabilities for these procedures were never reported.

The studies by Larsen *et al.* (1990) and Hynd *et al.* (1990) concentrated on asymmetry of the plana; although Hynd *et al.* (1990) examined other areas as well. These studies employed different methodologies. In the Hynd *et al.* (1990) study, the lengths of the plana were obtained from an extreme lateral sagittal MRI scan (reliability of measurement = 0.97 [left] 0.95 [right]).

Larsen *et al.* (1990) used coronal MRI sections moving anterior to posterior through the plana to obtain their measurements. Despite significantly different methodologies between the Hynd *et al.* (1990) and the Larsen *et al.* (1990) studies, similar findings of plana symmetry were found in the dyslexics in both studies.

While these studies were underway employing traditional MRI acquisitions, other researchers were developing morphometric acquisition procedures for 3D whole brain volumetric MRI scans (Filipek *et al.*, 1989; Jernigan *et al.*, 1990). Data from the use of these procedures that allowed for volumetric analysis of whole brain regions in other clinical populations proved useful in documenting differences in brain morphology. However, these procedures have not yet been employed in published reports on dyslexics. These procedures offer promise in MRI morphometric methodology, particularly in visualizing and measuring brain regions such as the thalamus and frontal lobe volume. Thus, new MRI acquisition procedures will enhance the options available to researchers in examining brain morphology, although what one examines and how it is measured will continue to be issues.

Steinmetz *et al.* (1989) for example, employed this acquisition procedure and demonstrated clearly that they afforded a much better methodology in visualizing and measuring the plana because they are capable of presenting thin, gapless slices of the brain. Steinmetz and his colleagues have made a number of recent contributions in this regard but he has also refocused our attention on basic neuroanatomy.

In a very important study, Steinmetz *et al.* (1990) examined sulcal topography of the parietal opercular region and found that tracings of the sulcal patterns revealed large but systematic differences in the morphology in this region. The different sulcal patterns underscored a reciprocal relationship with the size of the planum temporale and the occipitoparietal cortex. Leonard (personal communication, July 1991) examined these sulcal patterns in dyslexia and found that dyslexics evidenced the least common patterns of sulcal topography. Consequently, it would seem that there are other, more neuroanatomically-tied approaches to examining brain morphology in developmental dyslexia as well.

Neurolinguistic/neurobiological theory has clearly served us well to date in examining the presumed neurological etiology in developmental dyslexia. An overview of this literature suggests that neurolinguistic theory needs further articulation with regard to executive and subcortical processes that must interact with the perceptual-linguistic system of reading acquisition. New brain imaging technology and approaches coupled with a more sophisticated assessment of neurolinguistic deficits in dyslexia may be expected to enhance significantly our understanding of how variability in brain ontongeny interacts with deficient language and reading ability in developmental dyslexia.

REFERENCES

Aaron, P. G. and Simurdak, J. E.: 1991, 'Reading disorders: Their nature and diagnosis', in J. E. Obrzut and G. W. Hynd (eds.), *Neuropsychological Foundations of Learning Disabilities*, Academic Press, New York, pp. 519–548.

Alexander, M. P. and LoVerme, S. R., Jr.: 1980, 'Aphasia after left hemispheric intracerebral hemorrhage', *Neurology* **20**, 1193–1202.

Campbell, S. and Whitaker, H.: 1986, 'Cortical maturation and developmental neurolinguistics', in J. E. Obrzut and G. W. Hynd (eds.), *Child Neuropsychology: Theory and Practice*, Vol. 1, Academic Press, New York, pp. 55–72.

Cappa, S. F. and Vignolo, I. A.: 1979, ''Transcortical' features of aphasia following left thalamic hemorrhage', *Cortex* **15**, 121–130.

Chase, C. H. and Tallal, P.: 1991, 'Cognitive models of developmental reading disorders', in J. E. Obrzut and G. W. Hynd (eds.), *Neuropsychological Foundations of Learning Disabilities*, Academic Press, New York, pp. 199–240.

Cicerone, K. D., Lazar, R. M. and Shapiro, W.: 1983, 'Effects of frontal lobe lesions on hypothesis sampling during concept formation', *Neuropsychologia* **21**, 513–524.

Drake, W.: 1968, 'Clinical and pathological findings in a child with developmental learning disability', *Journal of Learning Disabilities* **1**, 468–475.

Duffy, F. H., Denckla, M., Bartels, P. H., Sandini, G. and Kiessling, L. S.: 1980, 'Dyslexia: Automated diagnosis by computerized classification of brain electrical activity', *Annals of Neurology* **7**, 421–428.

Eidelberg, D. and Galaburda, A. M.: 1982, 'Symmetry and asymmetry in the human posterior thalamus; I. Cytoarchitectonic analysis in normal persons', *Archives of Neurology* **39**, 325–332.

Eidelberg, D. and Galaburda, A. M.: 1984, 'Inferior parietal lobule: Divergent architectonic asymmetries in the human brain', *Archives of Neurology* **41**, 843–852.

Filipek, P. A., Kennedy, D. N., Caviness, V. S., Rossnick, S. L., Spraggins, T. A., and Starewicz, P. M.: 1989, 'Magnetic resonance imaging-based morphometry: Development and application to normal subjects', *Annals of Neurology* **25**, 61–67.

Flechsig, P.: 1908, *Zentralblatt Neurologie-Psychiatrie* **27**, 50.

Galaburda, A. M. and Eidelberg, D.: 1982, 'Symmetry and asymmetry in the human posterior thalamus: II. Thalamic lesions in a case of developmental dyslexia', *Archives of Neurology* **39**, 333–336.

Galaburda, A. M. and Kemper, T. L.: 1979, 'Cytoarchitectonic abnormalities in developmental dyslexia: A case study', *Annals of Neurology* **6**, 94–100.

Galaburda, A. M., Sanides, F. and Geschwind, N.: 1978, 'Human brain: Cytoarchitectonic left-right asymmetries in the temporal speech region', *Archives of Neurology* **35**, 812–817.

Galaburda, A. M., Sherman, G. F., Rosen, G. D., Aboitiz, F. and Geschwind, N.: 1985, 'Developmental dyslexia: Four consecutive patients with cortical anomalies', *Annals of Neurology* **18**, 222–233.

Geschwind, N. and Galaburda, A.: 1985, 'Cerebral lateralization: Biological mechanisms, associations, and pathology: A hypothesis and a program for research', *Archives of Neurology* **42**, 428–459, 521–522, 634–654.

Geschwind, N. and Levitsky, W.: 1968, 'Human brain: Left-right asymmetries in temporal speech region', *Science* **161**, 186–187.

Haslam, R. H., Dalby, J. T., Johns, R. D. and Rademaker, A. W.: 1981, 'Cerebral asymmetry in developmental dyslexia', *Archives of Neurology* **38**, 679–682.

Hier, D. B., LeMay, M., Rosenberger, P. B. and Perlo, V. P.: 1978, 'Developmental dyslexia: Evidence for a subgroup with a reversal of cerebral asymmetry', *Archives of Neurology* **35**, 90–92.

Hooper, S. and Hynd, G. W.: 1985, 'Differential diagnosis of subtypes of developmental dyslexia with the Kaufman Assessment Battery for Children (K-ABC)', *Journal of Clinical Child Psychology* **14**, 145–152.

Hugdahl, K., Wester, K. and Asbjornsen, A.: 1990, 'The role of the left and right thalamus in language asymmetry: Dichotic listening in Parkinson patients undergoing stereotactic thalamotomy', *Brain and Language* **39**, 1–13.

Humphreys, P., Kaufman, W. E. and Galaburda, A. M.: 1990, 'Developmental dyslexia in women: Neuropathological findings in three patients', *Annals of Neurology* **28**, 727–738.

Huttenlocher, P. R.: 1990, 'Morphometric study of human cerebral cortex development', *Neuropsychologia* **28**, 517–527.

Hynd, G. W. and Cohen, M.: 1983, *Dyslexia: Neuropsychological Theory, Research and Clinical Differentiation*, Alyan & Bacon Publishers, Needham Heights, MA.

Hynd, G. W., Connor, R. T. and Nieves, N.: 1988, 'Learning disability subtypes: Perspectives and methodological issues in clinical assessment', in M. G. Tramontana and S. R. Hooper (eds.), *Assessment Issues in Child Neuropsychology*, Plenum Publishing Corporation, New York, pp. 281–312.

Hynd, G. W. and Hynd, C. R.: 1984, 'Dyslexia: Neuroanatomical/neurolinguistic perspectives', *Reading Research Quarterly* **19**, 482–498.

Hynd, G. W., Marshall, R. and Gonzalez, J.: 1991, 'Learning disabilities and presumed central nervous system dysfunction', *Learning Disabilities Quarterly* **14**, 283–286.

Hynd, G. W. and Semrud-Clikeman, M.: 1989, 'Brain morphology in dyslexia', *Psychological Bulletin* **106**, 447–482.

Hynd, G. W., Semrud-Clikeman, M., Lorys, A. R., Novey, E. and Eliopoulos, D.: 1990, 'Brain morphology in developmental dyslexia and attention deficit disorder/hyperactivity', *Archives of Neurology* **47**, 919–992.

Jernigan, T., Press, G. A., Hesselink, J. R.: 1990, 'Methods for measuring brain morphologic features on magnetic resonance images', *Archives of Neurology* **47**, 27–32.

Johnson, D. J.: 1986, 'Remediation for dyslexic adults', in G. T. Pavlidis and D. F. Fisher (eds.), *Dyslexia: Its Neuropsychology and Treatment*, Wiley, New York, pp. 249–262.

Kelly, J. P.: 1985a, 'Anatomical basis of sensory perception and motor coordination', in E. R. Kandel and J. H. Schwartz (eds.), *Principles of Neural Science*, American Elsevier, New York, pp. 222–243.

Kelly, J. P.: 1985b, 'Auditory system', in E. R. Kandel and J. H. Schwartz (eds.), *Principles of Neural Science*, American Elsevier, New York, pp. 396–408.

Keogh, B.: 1986, 'A marker system for describing learning-disabilities samples', in S. Ceci (ed.), *Handbook of Cognitive, Social, and Neuropsychological Aspects of Learning Disabilities*, Vol. 1, Erlbaum, Hillsdale, NJ, pp. 81–94.

Larsen, J. P., Høien, T., Lundberg, I. and Ödegaard, H.: 1990, 'MRI evaluation of the size and symmetry of the planum temporale in adolescents with developmental dyslexia', *Brain and Language* **39**, 289–301.

Leisman, G. and Ashkenazi, M.: 1980, 'Aetiological factors in dyslexia: IV. Cerebral hemispheres are functionally equivalent', *Neuroscience* **11**, 157–164.

LeMay, M.: 1981, 'Are there radiological changes in the brains of individuals with dyslexia?', *Bulletin of the Orton Society* **31**, 135–141.

Leonard, C.: 1991, University of Florida, School of Medicine.

Liberman, I. Y., Shankweiler, D., Fisher, F. W. and Carter, B.: 1974, 'Explicit syllable and phoneme segmentation in the young child', *Journal of Experimental Child Psychology* **18**, 201–212.

Luria, A. R.: 1980, *Higher Cortical Functions in Man*, Plenum Press, New York.

Mateer, C. A. and Ojemann, G. A.: 1983, 'Thalamic mechanisms in language and memory', in S. Segalowitz (ed.), *Language Functions and Brain Organization*, Academic Press, New York, pp. 171–191.

Mayeux, R. and Kandel, E. R.: 1985, 'Natural language, disorders of language, and other localizable disorders of cognitive functioning', in E. R. Kandel and J. Schwartz (eds.), *Principles of Neural Science*, 2nd edition, Elsevier Science Publishing Company, Inc., New York, pp. 688–703.

Obrzut, J. E.: 1991, 'Hemisphere activation and arousal asymmetry in learning-disabled children', in J. E. Obrzut and G. W. Hynd (eds.), *Neuropsychological Foundations of Learning Disabilities*, Academic Press, New York, pp. 179–198.

Ojemann, G. A.: 1975, 'Language and the thalamus: Object naming and recall during and after thalamic stimulation', *Brain and Language* **2**, 101–120.

Parkins, R., Roberts, R. J., Reinarz, S. J. and Varney, N. R.: 1987, 'CT asymmetries in adult developmental dyslexics', paper presented at the annual convention of the International Neuropsychological Society, Washington, DC.

Pirozzolo, F.: 1979, *The Neuropsychology of Developmental Reading Disorders*, Fraeger Publishers, New York.

Rosenberger, P. B. and Hier, D. B.: 1980, 'Cerebral asymmetry and verbal intellectual deficits', *Annals of Neurology* **8**, 300–304.

Rubens, A. B., Mahowald, M. W. and Hutton, J. T.: 1976, 'Asymmetry of the lateral (sylvian) fissures in man', *Neurology* **26**, 620–624.

Rumsey, J. M., Dorwart, R., Vermess, M., Denckla, M. B., Kruest, M. J. P. and Rapoport, J. L.: 1986, 'Magnetic resonance imaging of brain anatomy in severe developmental dyslexia', *Archives of Neurology* **43**, 1045–1046.

Sandson, J. and Albert, M. L.: 1984, 'Varieties of perseveration', *Neuropsychologia* **22**, 715–732.

Satz, P.: 1991, 'The Dejerine hypothesis: Implications for an etiological reformation of developmental dyslexia', in J. E. Obrzut and G. W. Hynd (eds.), *Neuropsychological Foundations of Learning Disabilities*, Academic Press, New York, pp. 99–112.

Semmes, J., Weinstein, S., Ghent, L. and Teubner, H.-L.: 1963, 'Correlates of impaired orientation in personal and extrapersonal space', *Brain* **86**, 747–772.

Semrud-Clikeman, M., Hynd, G. W., Novey, E. S. and Eliopulos, D.: 1991, 'Dyslexia and brain morphology: Relationships between neuroanatomical variation and neurolinguistic performance', *Learning and Individual Differences* **3**, 225–242.

Smith, S., Pennington, B., Kimberling, W. J. and Ing, P. S.: 1990, 'Familial dyslexia: Use of genetic linkage data to define subtypes', *Journal of the American Academy of Child and Adolescent Psychiatry* **29**, 204–213.

Steinmetz, H., Ebeling, U., Huang, Y. and Kahn, T.: 1990, 'Sulcus topography of the parietal opercular region: An anatomic and MR study', *Brain and Language* **38**, 515–533.

Steinmetz, H., Rademacher, J., Huang, Y., Hefter, H., Zilles, K., Thron, A. and Freund, H.-J.: 1989, 'Cerebral asymmetry: MR planimetry of the human planum temporale', *Journal of Computer Assisted Tomography* **13**, 996–1005.

Tallal, P., Ross, R. and Curtiss, S.: 1989, 'Familial aggregation in specific language impairment', *Journal of Speech and Hearing Disorders* **54**, 167–173.

Von Economo, C. and Horn, L.: 1930, *Zeitschrift für die gesamte Neurologie und Psychiatrie* **130**, 678.

Wada, J. A., Clarke, R. and Hamm, A.: 1975, 'Cerebral hemispheric asymmetry in humans', *Archives of Neurology* **32**, 239–246.

Weinberger, D. R., Luchins, D. J., Morihisa, J. and Wyatt, R. J.: 1982, 'Asymmetrical volumes of the right and left frontal and occipital regions of the human brain', *Neurology* **11**, 97–100.

Witelson, S. F. and Pallie, W.: 1973: 'Left hemisphere specialization for language in the newborn', *Brain* **96**, 641–646.

Wolf, M., Bally, H. and Morris, R.: 1986, 'Automaticity, retrieval processes, and reading: A longitudinal study in average and impaired readers', *Child Development* **57**, 988–1000.

Yule, W. and Rutter, M.: 1976, 'Epidemiology and social implications of specific reading retardation', in R. M. Knights and D. J. Bakker (eds.), *The Neuropsychology of Learning Disorders*, University Park Press, Baltimore, MD, pp. 25–39.

DIRK J. BAKKER

THE WILLING BRAIN OF DYSLEXIC CHILDREN

ABSTRACT. Theoretical and empirical evidence is available to show that initial and advanced reading are primarily mediated by the right and left cerebral hemisphere, respectively. Disturbances in learning to read can be explained by assuming that some children shift from right to left in the hemispheric mediation of reading too late (P-type dyslexia) and some others do so too early (L-type dyslexia). P- and L-type dyslexia can be treated by stimulation of the left and right hemisphere, respectively. Such stimulation can be accomplished by the presentation of reading materials in the lateral visual and/or tactile fields. The results of recent research suggests that left versus right hemisphere stimulation has a differential effect on reading accuracy and speed.

INTRODUCTION

Reading concerns the processing of written language and since written language is language, reading is assumed to be primarily mediated by the left cerebral hemisphere in most individuals. Taking this a step further leads to the assumption that reading failure is somehow due to failure in the functioning of the left hemisphere. This is indeed so, as seems evident from the loss of reading ability that may follow an acquired lesion of the left rather than of the right hemisphere.

But what about the nine year old boy with agenesis of the right hemisphere, who was recently referred to our institute because of his inability to learn to read? He was able to speak and to understand speech to a degree that enabled him to communicate with others. Does this case, and other cases like it, indicate that integrity of the right hemisphere is a requirement for the emergence of initial reading?

NORMAL AND DISTURBED LEARNING TO READ

There is currently quite some evidence to show that normal reading is, in an initial stage predominantly mediated by the right hemisphere. Licht (1988; Licht *et al.*, 1988) for instance, carried out a longitudinal electrophysiological study with kindergarten children who were followed for four years. The children, who were taught to master a number of printed words at the outset of the study, were given, over the course of the study, these words flashed in the central visual field. Principal components scores of word elicited potentials, recorded at left and right hemispheric locations, were

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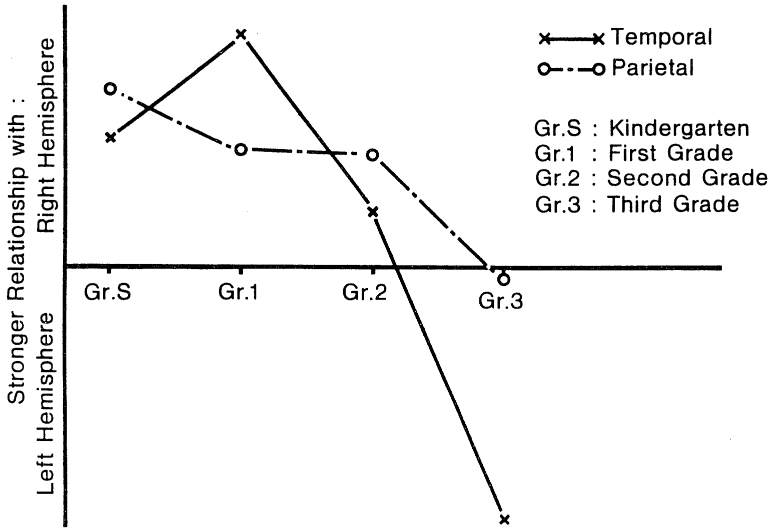

Fig. 1. Development of the relationship between reading/language ability and hemispheric activity, as measured at temporal and parietal sites of the brain (after Bakker, 1990).

correlated with factor scores on reading and spelling tests. As indicated in Figure 1 the association between hemispheric activity and reading/spelling performance changed with age, the association being strongest for the right hemisphere during the first years and for the left hemisphere during the last years of the study. Such a hemisphere–reading/spelling relationship was not found for potentials elicited by pictures.

There is also neuropsychological evidence to show that initial reading is predominantly mediated by the right hemisphere and advanced reading by the left hemisphere. Carmon *et al.* (1976) found in a visual halffield experiment, a right field advantage for verbal material at older primary school ages but an absence of or a left field advantage at younger school ages. Silverberg *et al.* (1979) demonstrated in an investigation with Israeli adolescents studying English as a second language, a right and left field advantage to English words flashed in the hemi-fields for experienced and novice students, respectively.

Much research has been done on the relationship between dichotic ear advantage and reading performance in normal and dyslexic readers. In most of these studies a relationship between proficient reading and a right ear advantage was almost invariably predicted. Indeed, proficient reading was often found to be accompanied by a right ear advantage and poor reading, though less often, to be accompanied by diminished right ear advantage or by a left ear advantage. However, evidence is also available to show that normal reading is associated with a left ear advantage in an initial stage of reading and with a right ear advantage in an advanced stage of reading. Finally, longitudinal psychometric research has shown (Fletcher and Satz, 1980) that verbal test results at the kindergarten age are predictive of reading performance at older primary school ages and visuo-spatial test results of reading performance at younger ages.

In conclusion, evidence is available from a variety of sources to show that early and advanced reading is primarily subserved by the right and left cerebral hemispheres, respectively, and that a hemispheric shift in the mediation of reading occurs at some point during the learning to read process. One might wonder why this may be the case. A possible answer to this question emerges from considering the differences between initial and advanced reading. Imagine a seven year old novice, and a twelve year old advanced reader who are given the same text to read. Since letter shapes are new for the novice reader, visuo-spatial text analysis will be prominent. However, as Fries (1963) suggested, perceptual analysis becomes automatic during advanced reading, at which time (here in the case of our twelve year old) the syntactical and semantic aspects of the text have become more salient. Smith (1971) agreed that the novice reader crosses the bridge between surface structure and meaning from the side of the surface structure and the advanced reader from the meaning side. Thus, the advanced reader seems to invest most effort in the processing of syntax and meaning whereas perceptual analysis is prominent, alongside syntactic and semantic processing, in early reading. The developmental shift from a prevalence of visuo-spatial reading strategies to a prevalence of semantic–syntactic reading strategies thus seems paralleled by a developmental shift in predominant right hemispheric reading subservience to a predominant left hemispheric reading subservience.

TREATMENT OF DYSLEXIA

What may one expect if the hemispheric shift of reading subservience does not take place, or if the shift was to occur prematurely? In the first case, the child will continue to rely predominantly on right hemispheric reading strategies, as will be reflected by a slow and fragmented yet relative accurate style of reading. This type of reading disturbance has been called P-type dyslexia (Bakker, 1990). In the case where the shift was to occur prematurely, one may expect an 'imitation' – as it were – of fluent reading, that is to say text processing will be fast but inaccurate since the reader will tend to overlook the perceptual features of the text. This type of reading disturbance has been called L-type dyslexia. Differentiation of P- and

L-type dyslexia takes place along the dimensions of speed and accuracy of reading: P-dyslexics are relatively slow, accurate readers, whereas L-dyslexics are relatively fast and inaccurate.

Much effort has been invested in studying the validity of the P/L-classification. Electrophysiological, biopsychological and psycholinguistic evidence are now available in support of the validity of the P/L-classification (Bakker *et al.*, 1991). Licht (this volume) reports on the outcomes of these studies in his contribution where he will discuss possible mechanisms underlying P- and L-dyslexia.

Assuming that P-dyslexics have gotten stuck in the generation of right hemispheric reading strategies and that L-dyslexics, in contrast, have more or less skipped that phase of reading acquisition, what sort of treatment should these two types of dyslexia be given? An answer to this question that is logical, as well as simple, is: stimulate the left cerebral hemisphere in P-type dyslexia and the right cerebral hemisphere in L-type dyslexia. However logical and simple this answer may be, it gives rise to a more fundamental question, namely, whether brain areas or systems will respond to stimulation by durable stimulation-induced changes. In other words, is there evidence available to attest that the brain is an environment-dependent variable?

There is overwhelming evidence, indeed, that brain structure and function can be affected by psychological and educational stimulation. Among the brain parameters that have been demonstrated to change as a durable response to such stimulation are cortical weight and thickness, size of neuronal cell bodies, number of dendritic branches and synapses, amount of various neurotransmitter substances, and electrophysiological activity (Renner and Rosenzweig, 1987). On the basis of these findings, it seems warranted to expect hemispheric changes in dyslexic children as a result of appropriate neuropsychological stimulation. Such stimulation can be accomplished in P-dyslexics by the presentation of printed materials in the right visual field and/or to the fingers of the right hand. This information will be projected to the contralateral, that is the left, cerebral hemisphere. Appropriate neuropsychological stimulation in L-dyslexics can be accomplished by the presentation of written materials in the left visual field and/or to the fingers of the left hand, in order to stimulate the right cerebral hemisphere. A computer program, called HEMSTIM, is now commercially available (from: The Center of 'Information Technology for the Handicapped', Patrijsweg 36, 2289 EX Rijswijk (ZH), the Netherlands) for hemisphere specific stimulation (HSS) via the visual halffields. The program entails the presentation of words – in any language – in the left or right visual field. Eye-fixation is controlled by requiring the child to move a cursor into a square located in the center of a monitor, which is only possible if the child keeps the eyes fixated on the square. As soon as cursor and square fuse, a word is triggered to the left or right of the center of the monitor. Words can be presented for any duration and in a multitude of typefaces.

A number of experimental group, single-case, and clinical studies have been conducted with HEMSTIM and experimental versions of this program, as well as with the tactile version of HSS (stimulation via the fingers of the right or left hand). The results of the various studies warrant the general conclusion that HSS brings about durable electrophysiological changes in the brain, that reading accuracy generally improves in L-dyslexia and fluency in P-dyslexia as a result of HSS and that a number of problems remain to be solved (Bakker, 1990).

STIMULATION OF THE RIGHT VERSUS THE LEFT CEREBRAL HEMISPHERE

Rather than discussing the various outcomes of these studies – the majority has been published in readily accessible journals – I would like to raise an issue for discussion on the possible mechanisms underlying the HSS effects. Physiological and behavioral changes are merely a reflection of the mechanism(s) affected by the stimulation; they are not the mechanism(s) itself. It has been suggested that the mechanism affected by HSS concerns arousal and attention. "... Bakker stimulated only the 'deficient' hemisphere and not the 'good' hemisphere in his children ... I would predict that, if Bakker had done similar stimulation of the 'good' hemisphere in these children, then this results may have been even better" (Morris, 1989, p. 189). The 'deficient' hemisphere in L-dyslexics is the right one and the 'good' hemisphere is the left one; vice versa holds for P-dyslexics. (It is somewhat tricky to speak of 'deficient' and 'good' hemispheres, 'deficient' and 'good' should be read as 'deficient' and 'good' *in the control of the subject's reading*.)

Morris' prediction is based on the assumptions that HSS selectively activates or primes each hemisphere which will lead to a, hemi-field related, narrowed focus of attention. Thus, the presentation of information in either the right or left visual field causes a focusing of attention, which in turn causes reading to improve. In other words, it is suggested that it does not matter much whether (verbal) information is presented in the right or left visual field, in both cases attention will be focused and that is why in both cases similar improvements in reading are to be expected. Morris is right that we never stimulated (challenged) the left hemispheres in L-dyslexics and the right one in P-dyslexics. At the time, we decided not to do so because this would have been unacceptable for the parents of the dyslexic children participating in our study. They had been informed of the rationale for and the results of a previous pilot investigation, indicating that left

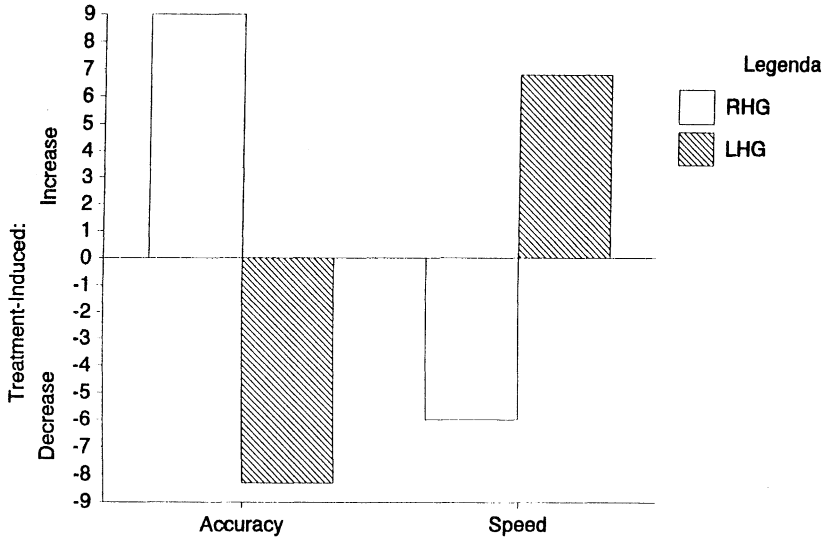

Fig. 2. Standardized pretest–posttest effects of right hemisphere stimulation (RHG) versus left hemisphere stimulation (LHG) on accuracy and speed of reading in L-type dyslexic children.

hemisphere stimulation in P-dyslexics and right hemisphere stimulation in L-dyslexics are associated with improvements in scholastic achievement. However, since Morris' prediction, that right and left hemi-field stimulation in both L- and P-dyslexia will produce similar results, is based on solid arguments it was decided to perform a 'challenge' experiment (Bakker *et al.*, in preparation). L-type dyslexic children were randomly divided in two groups. One group received specific stimulation of the right hemisphere (RHG) and the other group of the left hemisphere (LHG), by flashing words to read in the left (RHG) and right (LHG) visual fields, respectively. A total of 14 treatment sessions were given, two sessions per week, each session lasting for 30–45 minutes. All subjects were pre- and posttested with a standardized word-reading test and a standardized sentence-reading test (WRT and SRT, respectively). Number of errors and speed of reading were registered and standardized (z-scores) across groups (RHG and LHG), within tests (WRT and SRT) and testing period (pretest and posttest). The z-scores of errors on the two tests were then averaged within testing periods, to establish a measure of accuracy of reading (AR). The z-scores of speed on the two tests were similarly averaged within testing periods, to establish a measure of speed of reading (SR). Pretest AR and posttest AR were subtracted to reveal the accuracy effect of HSS. Pretest SR and posttest SR similarly were subtracted to reveal the speed effect of HSS. Both effects are graphically represented in Figure 2. Stimulation of the right hemisphere in L-dyslexics, appeared, in accordance with our expectations, to enhance accuracy of reading and to lower reading speed. Stimulation of the left hemisphere, however, rather than producing similar results, appeared to diminish accuracy of reading and to enhance reading speed. In view of the opposite effects of right versus left hemispheric stimulation it does not seem likely that attention is the mechanism underlying the stimulation-induced changes in reading performance. At present we are trying to find an answer to the question whether the hemispheric effects of stimulation hold for dyslexic children in general, irrespective of the type of dyslexia.

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REFERENCES

Bakker, D. J.: 1990, *Neuropsychological Treatment of Dyslexia*, Oxford University Press, New York.

Bakker, D. J., Licht, R. and Van Strien, J. W.: 1991, 'Biopsychological validation of L- and P-type dyslexia', in B. P. Rourke (ed.), *Neuropsychological Validation of Learning Disability Subtypes*, Guilford Press, New York, pp. 124–139.

Bakker, D. J., Spyer, G. and Egbers, W.: (in preparation), 'Differential reading effects of right versus left hemispheric stimulation in dyslexic children'.

Carmon, A., Nachshon, I. and Starinsky, R.: 1976, 'Developmental aspects of visual hemifield differences in perception of verbal material', *Brain and Language* **3**, 463–469.

Fletcher, J. M. and Satz, P.: 1980, 'Developmental changes in the neuropsychological correlates of reading achievement: A six year longitudinal follow up', *Journal of Clinical Neuropsychology* **2**, 23–37.

Fries, C. C.: 1963, *Linguistics and Reading*, Holt, Rinehart & Whinston, New York.

Licht, R.: 1988, *Event-Related Potential Asymmetries and Word Reading in Children: A Developmental Study*, Quick Service, Enschede, the Netherlands.

Licht, R., Bakker, D. J., Kok, A. and Bouma, A.: 1988, 'The developmental of lateral event-related potentials (ERPS) related to word-naming: A four year longitudinal study', *Neuropsychologia* **26**, 327–340.

Morris, R.: 1989, 'Treatment of learning disabilities from a neuropsychological framework', in D. J. Bakker and H. van der Vlugt (eds.), *Learning Disabilities, Vol. 1: Neuropsychological Correlates and Treatment*, Swets & Zeitlinger, Lisse, the Netherlands, pp. 183–190.

Renner, M. J. and Rosenzweig, M. R.: 1987, *Enriched and Impoverished Environments: Effects on Brain and Behavior*, Springer-Verlag, New York.

Silverberg, R., Bentin, S., Gaziel, T., Obler, L. K. and Albert, M. L.: 1979, 'Shift of visual field preference for English words in native Hebrew speakers', *Brain and Language* **8**, 184–190.

Smith, F.: 1971, *Understanding Reading*, Holt, Rinehart & Whinston, New York.

ROBERT LICHT AND JOS VAN ONNA

DIFFERENCES IN COMPONENTS OF WORD RECOGNITION BETWEEN P- AND L-TYPE READING DISABILITY

ABSTRACT. On the basis of the 'balance' model developed by Bakker, two types of reading disability can be distinguished. One type (P-type) reads slowly and makes relatively many so-called time-consuming errors such as spelling, fragmentations and repetitions. The other type (L-type) reads hastily and reading errors are characterized by skipping or adding words or parts of words. In the present chapter, L- and P-type children are compared on a number of component tasks that tap different stages of information processing in word recognition. The results suggest that the poorer reading performance of L-type children is associated with problems in the visual analysis of letter arrays/graphemes, whereas the poorer performance of P-type children, may be largely attributed to problems on a lexical level (accessing and/or searching the lexicon).

INTRODUCTION

In the 'balance' model developed by Bakker (1981, 1983) the process of learning to read is described in terms of changes in word information processing (e.g. from visuo-spatial processing of words to semantic processing of words), as well as in terms of changes in underlying brain mechanisms involved in word recognition.

It is suggested in the model that beginning reading is characterized by an emphasis on visuo-perceptual processing of letters, and that right hemispheric functions are predominantly involved at this stage (due to the right hemispheric superiority in visuo-spatial analysis). In contrast, advanced reading is characterized by an emphasis on meaning abstraction of text and it is assumed that left hemispheric functions play a dominant role at this stage (see Licht, 1988 and Licht *et al.*, 1988). Bakker further hypothesized that two types of reading disturbances may develop. The first type is the P-type reading problem characterized by slow but accurate reading. It is assumed that the right hemisphere is *still too strongly* involved in reading in these children leading to a visuo-spatial reading strategy that is appropriate in initial stages of learning to read, but that is inadequate for learning to read fluently. The second type is the L-type reading problem that is characterized by fast but inaccurate, guessing-like reading that may indicate the use of a semantic reading strategy by these children. It is assumed that left hemispheric mechanisms are involved *too early* in the learning to read process.

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According to the information processing approach words can be read along an indirect or a direct route (Barron, 1986; Stanovich, 1986). The indirect or phonological route states that identification of words is attained through the generation of a phonological code by a stepwise translation of graphemes into phonemes. This word reading strategy will be found in the majority of beginning readers and in reading unfamiliar words. The direct or lexical route assumes that words can be identified directly on the basis of word specific features that are stored in word memory. This route will be used in reading familiar words and will be mostly used by fluent readers.

As has been described previously, L- and P-type children are classified on the basis of reading speed and type of reading errors. P-types are slow readers and make relatively many time-consuming errors (e.g. spelling, hesitations and fragmentations), whereas L-type children read hastily and inaccurately (making semantic errors, deletions and intrusions). A similar subtyping of reading disability on the basis of reading errors has also been proposed by Boder (1973) and Van der Leij (1983). Boder distinguishes between 'dysphonetic' and 'dyseidetic' dyslexia subtypes. Dysphonetics have difficulty in grapheme to phoneme translation, whereas dyseidetics have problems in using visual orthographic information in word recognition. Van der Leij distinguishes between 'spellers' and 'guessers' and assumes that 'guessers' prefer a direct word recognition strategy but have to guess word meaning due to insufficient processing of visuo-perceptual features of words. In contrast, 'spellers' keep relying on the slower, stepwise grapheme to phoneme translation strategy in reading. Frith (1985) proposes at least two types of reading disability that are characterized by problems in mastering phonological or orthographical skills, and that have to rely on visual word recognition and spelling strategies, respectively.

The different subtypes distinguished by Van der Leij, Boder and Frith largely overlap and, in view of the nature of processing deficits, seem to converge to two broad categories that are characterized by visual- and spelling-like reading behavior, respectively.

Licht (1989) and Neijens (1991) found that L- and P-type children can also be equated with 'guessers' and 'spellers', respectively, on the basis of errors in reading irregular and pseudowords. The finding that L-type children have most problems reading pseudowords (which call upon a phonological strategy), and that P-type children have most difficulty with irregular words (which require a lexical reading strategy), suggests that L-type children prefer a fast, direct word recognition strategy, whereas P-types rely on a slow and more elaborate phonological strategy.

In information processing models of reading several qualitatively different stages or components of processing in word recognition are assumed (Frederiksen, 1977, 1980; Seymour and MacGregor, 1984). Globally, the first stage concerns the analysis of visual features of words, which is followed by a stage of graphemic analysis of letters or lettergroups. The second stage is characterized by the phonological decoding of graphemes, whereas the third and fourth stage are associated with lexical/semantic processing and response generation (speech), respectively. Speed and accuracy of processing in these different stages or components can be tapped by tasks that call upon specific analyses of words (e.g. visual, phonological, lexical or semantic analysis), or that require specific responses to be made (e.g. reading aloud or decision making).

The purpose of the present study is to find out whether the difference in word recognition strategy between P- and L-type children can be attributed to differences in speed and accuracy of the visual analysis of words, or rather has to do with differences in processing on a higher, central level (lexical), or both. On the basis of earlier findings (Van der Leij, 1983; Licht, 1989), it was expected that L-type children would show problems in visual analysis of word features and graphemes, and that P-type children would show problems in using lexical (orthographic) information for word recognition. To test these hypotheses, a series of tasks tapping speed and accuracy of visual analysis of letter arrays and lexical and semantic analysis of words, were presented to L- and P-type children and normal readers.

METHOD

Subjects

Dyslexic children lagging one or more years on reading were selected from a large pool of children attending special schools. Children with reading disturbances that could be attributed to emotional problems, manifest neurological dysfunctions, or cultural factors, were excluded from participation. Fifteen P-type children and 18 L-type children (age: 9–12 years) were classified on the basis of their pattern of substantive and time-consuming reading errors during text reading (see for selection criteria Bakker and Vinke, 1985). A group of 18 normal readers (age: 9–12 years) from a normal primary school served as a control group. Table 1 depicts reading performance of the dyslexic children and the normal readers.

P- and L-type children were comparable in reading accuracy on standard Dutch reading tests for both word reading (one-minute-test; Brus and Voeten, 1973), and text reading (AVI; Van den Berg and te Lintelo, 1977) with a time limit, as well as for reading regular words without time pressure (WDT; Van Aarle and Vollebergh, 1986).

TABLE 1

Reading performance scores on Dutch word reading (one-minute-test) and text reading (AVI) tests, and on reading regular words (WDT) for P- and L-type children and normal controls.

	One-minute-test		AVI		WDT
P-type	32.5	(14.8)	3.7	(1.9)	2.7
L-type	38.3	(13.3)	4.3	(1.9)	2.9
Normal	67.6	(7.8)	8.1	(0.8)	0.2

Note: One-minute-test: number of words read correctly in 1 minute; AVI: reading level (speed and accuracy included); WDT: number of reading errors. Numbers between parentheses are s.d.'s.

Tasks

The following tasks were administered:

(A) A simple reaction time task (BRT) that required the child to respond as fast as possible upon the appearance of a four-letter stimulus on the screen. Since no stimulus processing was required, this task provides a measure of the time needed to detect and respond to a visual stimulus and is called the basic response speed.

(B) A visual scanning task (VSCAN), that required the child to determine whether all letters in a four-letter array were visually similar or not (e.g. aaaa or aaea). All letters were lower case letters. On half the trials a different letter was embedded within three similar letters. This task provides information about speed and accuracy of visual analysis of letter arrays.

(C) A letter identification task (LIDEN). This task consisted of the presentation of four-letter arrays that were made up of lower and upper case letters (e.g. aAaa or aaBa). The child had to decide whether all letters had the same name identity. On half the trials the letters were not identical. This task provides information about speed and accuracy in analyzing letter identity.

(D) A lexical decision task (LEXD) that required the child to decide whether a presented word was a correct Dutch word or not. Twenty

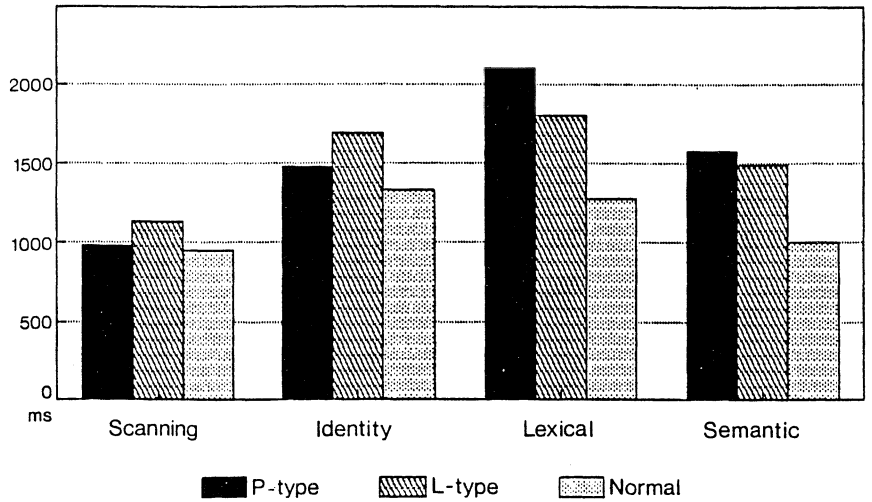

Fig. 1. Average response time for visual scanning, letter identity and lexical and semantic decision tasks in P- and L-type children and normal reading children.

trials of four-letter normal and pseudowords each were randomly presented. It is expected that decision time for normal words is shorter than for pseudowords, since the latter words call upon a slow, phonological reading approach.

(E) A semantic decision task (SEMD) that required the child to determine whether a presented word concerns an animal name or not. On half the trials stimulus words were animal words. This tasks provides information about the speed of word reading and analysis of word meaning.

The stimulus presentation time was 3000 msec in all tasks. Maximal response times allowed were 4000 msec.

Data Analysis

Average response times were calculated for each task and condition by averaging correct responses only. Outliers, i.e. response times that differed more than 2 s.d. from the mean response time of a condition, were removed prior to averaging. Separate ANOVAs with P-type, L-type and normal readers as grouping factor and conditions within tasks as a within factor, were performed on the average response times and error scores for each task.

TABLE 2

Average response times and standard deviations in the basic response task, visual scanning and letter identification tasks and in the lexical and semantic decision tasks for P- and L-type children and normal controls (N).

	BRT	Scan.	Ident.	Lex.	Sem.
P	339 (97)	981 (178)	1471 (336)	2099 (552)	1569 (412)
L	342 (97)	1133 (187)	1694 (272)	1803 (421)	1495 (346)
N	369 (111)	947 (158)	1323 (248)	1277 (288)	1015 (198)

TABLE 3

Average number of errors for same and different trials in the visual scanning and letter identity tasks and for no and yes trials in the lexical and semantic decision tasks for P- and L-type children and normal reading children (N).

	Scan.		Ident.		Lex.		Sem.	
	diff	same	diff	same	no	yes	no	yes
P	1.2	0.6	2.8	4.2	5.4	3.3	1.0	2.5
L	1.0	0.5	2.6	4.0	3.3	3.3	0.7	2.6
N	1.2	0.4	1.8	2.7	1.7	1.8	0.7	0.9

RESULTS

Average response times for each tasks are depicted in Figure 1 and Table 2, whereas average error scores are depicted in Table 3. Analysis of response times revealed that there were no significant differences between groups in basic response speed. In all other tasks, ‘different’ responses were associated with longer response times than ‘same’ responses. Analyses of the visual scanning and letter identification tasks revealed that L-type children showed longer response time on both the scanning and letter identity tasks than P-type children (152 and 223 ms longer, respectively) and normal readers (186 and 371 ms longer, respectively). P-type children were slower than normal readers in the letter identification task (151 ms slower) only.

Analysis of the lexical and semantic decision tasks, however, revealed that now P-type children were slower than L-type children in making lexical decisions (301 ms slower). Normal readers were again faster than

P- and L-type children in the lexical (825 and 555 ms faster, respectively), as well as in the semantic task (559 and 485 ms faster, respectively).

Analysis of error scores showed that L- and P-type children made more errors than normal readers in (a) the letter identification task, (b) on animal names in the semantic task (false negatives), and (c) on words (false negatives), as well as on pseudoword trials (false positives) in the lexical task. In addition, P-type children made most errors on pseudowords in the lexical task (false positives).

DISCUSSION

The goal of the present study was to find out whether P- and L-type children differ in speed and/or quality of processing in some of the components that can be distinguished in word recognition (Frederiksen, 1977, 1980). For this purpose a number of tasks were presented that tapped visual analysis of letter and grapheme arrays and lexical and semantic processing of words. It was expected that the guessing-like reading style of L-type children would be associated with insufficient analysis of letter features, whereas the slow, spelling-like reading style of P-type children would reflect problems in using lexical information for word recognition.

The finding that L-type children differed from both P-type children and normal readers in speed of visual scanning suggests that L-type children indeed have problems in the analysis of visual features of series of letters. This effect cannot be attributed to differences in basic response speed, since the groups of children did not differ in simple reaction times.

A closer look at the differences in response times between tasks can be obtained by subtracting the time needed to complete a simple component task from the time needed for a more complex component task. In this way, we find that the process of visual scanning takes about 642 ms in the P-type group and about 791 ms in the L-type group (VSCAN-BRT), whereas the process of letter identification takes about 561 ms more than scanning in L-type children and about 490 ms in P-type children (LIDEN-VSCAN). The longer response times found for letter identification in the L-type children may, on the one hand, result from their problems in analyzing visual features of letters, but may on the other hand also indicate that L-type children have difficulties in the stepwise analysis of graphemes. Since L-type children did not differ from P-type children in accuracy on both the scanning and letter identification tasks, the longer response times found for L-type readers may reflect problems in allocating effort or attention to this stage of letter analysis (LaBerge and Samuels, 1984).

As soon as words are presented and decisions have to be made about lexical properties, we see an opposite pattern in responses for P- and L-type children: now P-type children are slower than L-type children. The slower responses of P-type children cannot be attributed to deficits in the analysis of visual features, as we have discussed in the previous paragraph. Interestingly, the problems of P-type children are most pronounced when pseudowords have to be judged on being correct words or not. P-type children take about 1000 msec longer than normal readers and about 400 msec longer than L-type children for such a decision. In addition, P-type children, more frequently than L-type children and normal readers, make false positive errors in deciding that pseudowords are real words. It should further be noted, that P-type children differ only slightly from L-type children when it concerns time needed for semantic decisions. Therefore, the specific problem of P-type children seems to be in searching the lexicon for lexical (orthographic) information. The observation that the difference in response times between lexical and semantic decisions is highly similar for L-type children and normal readers, may indicate that the time needed to search for lexical information is rather normal in L-type children. The rather consistent difference between L-type and normal readers, however, may indicate that L-type children have problems in an earlier stage of word identification, e.g. analysis of word features and/or access to lexical information.

It has been suggested that the reliance on specific word recognition strategies by reading-disabled children may indicate a developmental arrest at a specific subskill in word recognition, as well as the effects of compensatory skills to overcome these problems (Frith, 1985). Tentatively, L-type children may have adopted a whole word or 'lexical' strategy to overcome their problems in analyzing letter features and graphemic information, which are prerequisites for mastering alphabetical reading skills. P-type children, having relatively intact skills in feature and graphemic analysis, may have to rely on a spelling strategy to attack words to overcome a lack in using lexical/orthographical information to speed up their reading.

In summary, L-type children have problems in the analysis of visual features of letter arrays and may therefore also have difficulties with the analysis of graphemic information. Their slower responses in lexical and semantic decision tasks relative to normal readers may be attributed to the aforementioned problems, and probably not to problems in speed of lexical search processes. In contrast, the poorer performance of P-type children when it concerns lexical processing, may largely be attributed to problems in searching and/or accessing the lexicon, problems that cannot be ascribed to deficits in the analysis of visual letter features and graphemic information.

REFERENCES

Bakker, D. J.: 1981, 'A set of brains for learning to read', in K. C. Diller (ed.), *Cognitive Growth and Development*, Brunner/Mazel, New York, pp. 56–71.

Bakker, D. J.: 1983, 'Hemispheric specialization and specific reading retardation', in M. Rutter (ed.), *Developmental Neuropsychiatry*, Guilford Press, New York, pp. 498–506.

Bakker, D. J., Licht, R. and Van Strien, J.: 1991, 'Biopsychological validation of L- and P-type dyslexia', in B. P. Rourke (ed.), *Neuropsychological Validation of Learning Disability Subtypes*, Guilford Press, New York, pp. 124–138.

Bakker, D. J. and Vinke, J.: 1985, 'Effects of hemisphere-specific stimulation on brain activity and reading in dyslexics', *Journal of Clinical and Experimental Neuropsychology* **7**, 505–525.

Barron, R. W.: 1986, 'Word recognition in early reading: A review of the direct and indirect access hypotheses', *Cognition* **24**, 93–119.

Boder, E.: 1973, 'Developmental dyslexia: A diagnostic approach based on three atypical reading patterns', *Developmental Medicine and Child Neurology* **15**, 663–687.

Brus, B. and Voeten, M. J.: 1973, *Een-minuut-test, vorm A en B, verantwoording en handleiding*, [One-minute-test, form A and B, background and manual], Berkhout, Nijmegen.

Frederiksen, J. R.: 1977, 'Assessment of perceptual, decoding, and lexical skills and their relation to reading proficiency', in A. M. Lesgold, S. D. Fokkema and R. Glaser (eds.), *Cognitive Psychology and Instruction*, Plenum Press, New York, pp. 153–169.

Frederiksen, J. R.: 1980, 'Component skills in reading: Measurement of individual differences through chronometric analysis', in R. E. Snow, P.-A. Federico and W. E. Montague (eds.), *Aptitude, Learning and Instruction*, Vol. I, Lawrence Erlbaum, Hillsdale, NJ, pp. 105–138.

Frith, U.: 1985, 'Beneath the surface of developmental dyslexia', in K. E. Patterson, J. C. Marshall and M. Coltheart (eds.), *Surface Dyslexia in Adults and Children*, Lawrence Erlbaum Associates, London, pp. 301–329.

LaBerge, D. and Samuels, S. J.: 1974, 'Towards a theory of automatic information processing in reading', *Cognitive Psychology* **6**, 293–323.

Licht, R.: 1988, *Event-Related Potential Asymmetries and Word Reading in Children: A Developmental Study*, Doctoral dissertation, Free University, Amsterdam.

Licht, R., Bakker, D. J., Kok, A. and Bouma, A.: 1988, 'The development of lateral event-related potentials (ERPs) related to word naming: A four year longitudinal study', *Neuropsychologia* **26**, 327–340.

Licht, R.: 1989, 'Reading disability subtypes: Cognitive and electrophysiological differences', in D. J. Bakker and H. van der Vlugt (eds.), *Learning Disabilities, Vol. I: Neuropsychological Correlates and Treatment*, Swets & Zeitlinger, Lisse, the Netherlands, pp. 81–103.

Neijens, L.: 1991, *Betrouwbaarheid en Validiteit van Classificatie in Type Dyslexie volgens het Balans Model* [Reliability and Validity of Dyslexia Subtype Classification According to the Balance Model], Master thesis, Free University, Amsterdam.

Seymour, P. H. K. and MacGregor, C. J.: 1984, 'Developmental dyslexia: A cognitive experimental analysis of phonological, morphemic, and visual impairments', *Cognitive Neuropsychology* **1**, 43–82.

Stanovich, K. E.: 1986, 'Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy', *Reading Research Quarterly* **21**, 360–407.

Van Aarle, E. J. M. and Vollebergh, M.: 1986, 'Raders en spellers: Wat is de betekenis van dit onderscheid in de groep zwakke lezers?' [Guessers and spellers: What is the meaning of this distinction in the group of poor readers?], *Pedagogische Studien* **63**, 339–346.

Van den Berg, R. M. and te Lintelo, H. G.: 1977, *AVI: Analyse van Individualiseringsvormen, Individualisering van het Leesonderwijs* [AVI: Analysis of Individual Reading Styles], Katholiek Pedagogisch Centrum, 's-Hertogenbosch, the Netherlands.

Van der Leij, A.: 1983, *Ernstige Leerproblem* [Severe Learning Problems], Swets & Zeitlinger, Lisse, the Netherlands.

FRANCISCO J. MARTOS

SPEED OF VISUAL INFORMATION PROCESSING IN DEVELOPMENTAL DYSLEXIA

Speed of Processing in Dyslexic Children

ABSTRACT. Our study compared 30 dyslexic with 30 retarded and 30 normal readers, aged between 7 and 14, in a task which allowed us to measure the reaction time of these three groups in three different conditions of stimuli presentation: (a) Physical Identity (PI), both stimuli were equal (i.e. A–A); (b) Name Identity (NI), the stimuli were physically different but had the same name and lexical value (i.e., A–a), (c) No identity (NOI), the stimuli were different in their physical appearance as well as in their name and lexical value (i.e. A–E). Within each group, the subjects were divided into three subgroups of 10 in accordance with the following chronological ages: 7–9, 10–11 and 12 years and upwards. Dependent variables were: reaction time in the PI condition; subtraction of the reaction time in the PI from the reaction time in the NI conditions (NI - PI); and total of errors in identification. The statistical analysis of the results showed that the speed of processing of the normal readers was faster than the other two groups in the PI conditions. The same pattern of results was found for the differences in reaction time between the NI and PI conditions (NI - PI). No differences were found among the three groups in the number of errors. Nor did we find differences between dyslexic and retarded readers in any dependent variable. With regard to the age factor, the results showed a general increase in the speed of processing of the three groups as age increased. However, this increase was considerably greater in the dyslexic group. The low rate of information processing present in the dyslexic children is explained as a result of a neurological or developmental delay. Further, the possibility that the slow speed of processing could produce a visual deficit in the dyslexic readers is also evaluated.

INTRODUCTION

A lot of research has related the dyslexic etiology to a slower speed of information processing in the different stages of the reading activity. Nevertheless researchers differ considerably in the meaning of this relationship. This disagreement could be summed up by two opposite views. On the one hand, there are authors who claim that the lower rate of information processing is the cause of the dyslexia. It is true that these authors disagree amongst themselves with regard to the exact stage at which the disturbance is produced and also with regard to the process responsible for the alteration. However, all of them maintain that the lower rate in visual information processing produces some kind of perceptual or visual deficit which is the direct cause of dyslexia. In short, they maintain that given the sequential nature of the reading processing, the lower rate in visual

C.K. Leong and R.M. Joshi (eds.), Developmental and Acquired Dyslexia, 51–59.

information processing at one stage would produce a stimulation overload in the visual system of the dyslexic. So a visual input may arrive at that stage before the current information has been completely processed. An information bottleneck would ensue leading to an incomplete processing or an integration of the stimuli. The mechanism underlying this pattern of events is that known as visual masking. As applied to dyslexia, this theory suggests that perception of a visual stimulus is impaired because the degraded output of the faulty stage provides an inadequate input for all later stages. The perceptual impairment could take a variety of forms such as erasures, substitution, or mirror reversal. What type of perceptual degradation occurs would depend on the function performed by the faulty processing stage. Examples of these points of view can be found in Arnett and Di Lollo (1979); Badcock and Lovegrove (1981); Di Lollo *et al.* (1983); Lovegrove *et al.* (19860, among others.

On the other hand, many other authors maintain that the slow speed of processing in dyslexic subjects is only apparent in those tasks requiring reading letters or words, semantical comprehension, etc. From this point of view, the low rate of processing only reflects the difficulty that dyslexics have with this kind of tasks. This difficulty would be more related to phonological coding problems than to perceptual problems. Examples of these positions can be found in Ellis and Miles (1981); Stanovich (1981); Bryant and Goswami (1987); Hulme (1988), and other researchers.

Taking all the discrepancies into account, we carried out our research with three objectives. Firstly, we tried to elucidate whether the differences in the speed of information processing between dyslexic and normal readers, are already evident in stages before lexical or phonological processing, or whether, on the contrary, the lexical access or phonological codification problems are what really produce the lower rate of processing in dyslexic children. Our second objective concerned the non-existence of a retarded reader control group in the majority of the studies referred to previously. Aaron (1989) has pointed out that the proper experimental design to be used in investigating the question of whether dyslexic readers have specific deficit requires the comparison between these subjects and retarded readers. In our research a retarded reader group was included alongside the dyslexic and normal reader groups. In this way, we were able to determine whether the low speed of information processing is a differential characteristic of the dyslexic children or whether, on the contrary, it is also present in other forms of reading disorders. Lastly, we wanted to find out whether the rate of information processing was related to the developmental aspects of the subjects.

METHOD

Subjects

The subjects were 90 children – 30 dyslexics, 30 retarded readers and 30 normal readers – aged between 7 and 14, selected from a group of 350 children who were attending six primary schools. The children were diagnosed as dyslexics in accordance with the following criteria: (a) reading age two years below their chronological age; (b) IQ over 95 in the WISC-R, and (c) no hearing or visual disability, brain damage or any kind of affective, educational or family problems which might influence or explain the reading difficulty.

Design

A 3 × 3 factorial design was used, the first factor being Reading Disability at three levels (Dyslexic, Retarded Readers and Normal Readers) and the second factor Age at three levels (7–9, 10–11 and over 12 years old). The three reading groups of 30 Ss each (21 male and 9 female) were formed according to the following criteria:

- Dyslexic Group: Reading Age 2 years behind chronological age; IQ > 95,
- Retarded Reader Group: Reading Age 2 years behind chronological age; IQ between 75 and 90,
- Normal Reader Group: Reading Age equal to or higher than chronological age; IQ > 95.

Each reading group was divided in turn into three subgroups of 10 subjects in accordance with the following chronological ages: 7–9 years, 10–11 years and 12 years upwards.

Apparatus

All stimuli were displayed on a three-channel Tachistoscope, Scientific Prototype (model N-1000s) made by Pharmaceutical Research and Developmental Company. The subject's responses and their latency were recorded on a Letica Printer Chronometer, model Le 130/100. The accuracy of this chronometer is of one millisecond and gives a printed record of the subjects' replies.

Experimental Task

The experimental task was similar to the one originally used by Posner and Mitchell (1967). A pair of letters was visually presented and the subject had to respond, as soon as possible, specifying whether the two letters were equal or different. The stimuli were a pair of capital or small letters. The height of each letter was 0.8 degrees of visual angle and the separation between the letters was of one degree. The task allows us to measure the latency of the subject's responses, according to three different conditions of stimuli presentation:

(1) Physical Identity (PI). Both letters were equal not only with regard to their lexical value but also in appearance (i.e. A–A).
(2) Name Identity (NI). The letters which formed the stimulus were identical in name and lexical value but different in their physical appearance (i.e. A–a).
(3) No Identity (NOI). The two letters were different in physical characteristics as well as in name and lexical value (i.e. A–E).

Two of these conditions, PI and NI, are different in the number of levels of processing involved. In order to answer under the PI condition the subjects only have to compare the perceptual patterns of the stimuli while under the NI condition there is an added process, this being access to the lexical code, whereby the subject is able to recognize that although the stimuli are different in their physical characteristics, they represent the same letter. The NI condition includes the PI condition. Thus by subtracting the PI condition reaction time from that of the NI condition (NI - PI) we are able to isolate the time required by the subject to access the lexical code and to recognize the physically different letters. The NOI condition was only introduced to prevent the subjects from answering quickly even though they had not had time to identify the stimulus. So in the PI condition just as with the NI condition, the subjects had to answer as quickly as possible that both letters were the same. The answer had to be 'different' in the NOI condition.

Procedure

The subjects were seated in a semi-dark room and viewed the display surface through a viewing hood. Subjects initiated each display by pressing a button. Two push buttons, hand held by the subjects, were used for indicating the response (two-alternative forced choice) in each condition of stimuli presentation. Upon entering the laboratory, the subject was given full instructions regarding stimuli and responses. To facilitate comprehension, several stimuli analogous to the real display stimuli were used. Subject were then introduced to the experimental task under 'training' condition.

The stimuli were presented in such a way that when the subject pressed the button a fixation dot appeared on the display for 500 milliseconds.

Immediately afterwards the stimuli appeared and remained visible until the subject pressed the button which corresponded to the response. After a brief interval of five seconds the next trial began. A total of 84 stimuli were presented – 28 for each stimulation condition. The order of presentation had been randomized previously. The subject's final score on any one stimuli presentation condition consisted of the average reaction time obtained for each stimulus.

RESULTS

Separate 3 × 3 (Reading Disability × Age) ANOVAS were carried out for the three dependent variables used: (1) reaction time in the PI condition; (2) subtraction of the reaction time in the PI condition from the reaction time in the NI condition (NI - PI); and (3) number of identification errors.

In the PI condition just as in the NI - PI, the results showed the existence of significant effects both in the Reading Disability factor and the Age factor. The analyses carried out by means of the Newman–Keuls Test (see Table 1) showed that the reaction time of the normal readers was significantly shorter than that of the dyslexic and retarded readers. The same pattern of results was found in the subtraction of reaction time in the PI condition from the reaction time in NI condition (NI - PI). However, there were no differences at all between dyslexic and retarded readers (see Table 1).

As can be observed in Table 1, no significant effects were found in any factor with regard to the number of errors made by the subjects.

With regard to Age, the results showed the existence of significant main effects both in the PI condition and in the NI - PI (see Figures 1 and 2). In general, the reaction time of the subjects decreased as age increased. Nevertheless, as is evident in Figure 1, the interaction Reading Disability by Age was also significant in the PI condition. The analysis of this interaction revealed that the increase in the speed of response was only significant in the dyslexic group.

DISCUSSION

Our results show that dyslexic readers are slower than normal readers in the speed at which they process visually presented stimuli. Besides, this lower rate of processing is already manifest in the PI condition, where the subjects are required only to distinguish between two physically different stimuli. These results are consistent with those obtained by Di Lollo *et al.* (1983) and Lovegrove *et al.* (1986), in the sense that the deterioration

TABLE 1

Means and standard deviations of reaction times (msec) in the condition of Physical Identity (PI); of reaction times of Physical Identity subtracted from reaction times of Name Identity condition (NI - PI); and means and standard deviations of the number of errors as a function of reading disability. Significant differences between the groups (Newman–Keuls Test) are indicated by a segment with an asterisk.

	NORMAL	RETARDED	DYSLEXIC
PI	660 (122)	949 (131)	911 (158)
	NORMAL vs RETARDED *		
	NORMAL vs DYSLEXIC *		
NI-PI	136 (66)	223 (118)	223 (92)
	NORMAL vs RETARDED *		
	NORMAL vs DYSLEXIC *		
ERRORS	1.53 (1.02)	1.03 (0.95)	1.23 (0.89)

* $p < 0.01$

of dyslexic subjects is produced in the early stages of visual information processing. It cannot be argued against this interpretation of the results, that the differences found between dyslexic and normal readers can be explained by the higher difficulty of the dyslexic readers in recognizing letters. The number of errors made by dyslexic and normal readers is not significantly different. In addition, the number of errors was very low in all the groups, confirming that the task was very easy for all the subjects.

These results are even more interesting when these data are related to results of research showing the existence of altered eye movement patterns in dyslexic children (Martos and Vila, 1990; Pavlidis, 1985, 1990). In accordance with the results of our research we could argue that the greater number of eye movements, both saccadic and regressive, in the

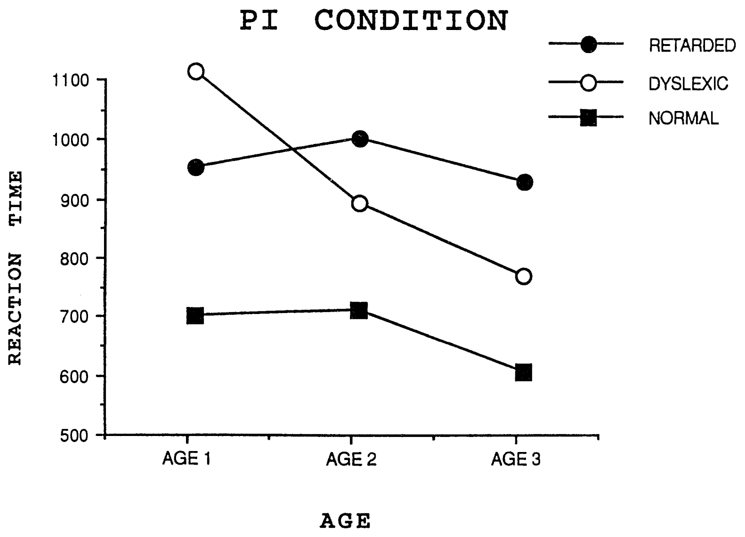

Fig. 1. Mean values (msec) of the reaction time in the Physical Identity condition (PI) of stimuli presentation in the dyslexic, retarded and normal groups as a function of age.

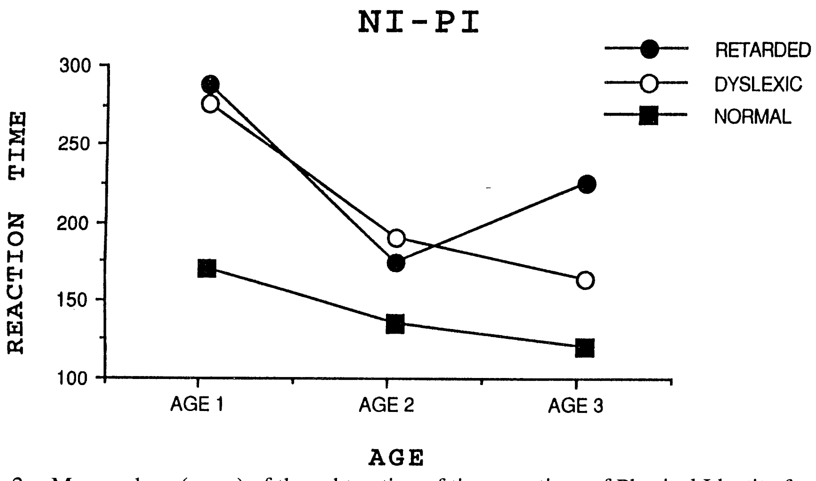

Fig. 2. Mean values (msec) of the subtraction of time reactions of Physical Identity from time reactions of Name Identity conditions (NI - PI) in the dyslexic, retarded and normal groups as a function of age.

dyslexic subjects could be a consequence of their lower rate of visual information processing. In order to avoid the masking effect produced by the arrival of the following stimulus, when the previous one has not yet been processed, the dyslexic subjects move their eyes, avoiding, by means of the saccadic suppression mechanism (Breitmeyer, 1983; Breitmeyer and Ganz, 1976), the degrading masking effect which the arrival of the following icon involves when the previous one still persists.

However, there are other data in our research which oblige us to be specially careful with regard to our conclusions. Firstly, we must take into account that there are no significant differences between dyslexic and retarded readers in any task. This result makes it clear that the slow speed of visual information processing is not a distinctive characteristic of dyslexic children.

With regard to age, our data show that the increase in processing speed generally corresponds to an increase in age. These results are consistent with those obtained by Kail (1991). Kail has recently shown that the processing speed in normal subjects increases linearly in relation to age. This is evident both in childhood and adolescence, even though the increase is less the older the subjects are. Our results, nevertheless, are of special interest when looking at the data of dyslexic readers. As can be observed in Figure 1, the decrease in reaction time of the dyslexic subjects in the PI conditions, is much greater than that of other subjects. In spite of the fact that the dyslexic subjects' reaction time is longer than that of other subjects in the first age level, their reaction time improves progressively and in such a way that, by the time the dyslexic readers reach the last age level, the difference between them and other subjects has decreased considerably. This improvement is even greater in NI - PI (Figure 2). These results could reveal some kind of maturational or neurological delay in dyslexic readers, from which they recuperate progressively.

Finally, another important consideration regarding our results concerns the fact that the dyslexic readers are also slower than normal readers in the NI - PI dependent variable. It is said that this subtraction represents lexical access time. Accordingly, the lower rate of information processing seems to reflect a general characteristic of dyslexic subjects which is present in all kinds of processing, even in that not related to visual information processing.

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REFERENCES

Aaron, P. G.: 1989, 'Qualitative and quantitative differences among dyslexic, normal and nondyslexic poor readers', *Reading and Writing: An Interdisciplinary Journal* **1**, 291–308.

Arnett, J. L. and Di Lollo, V.: 1979, 'Visual information processing in relation to age and to reading ability', *Journal of Experimental Child Psychology* **27**, 143–152.

Badcock, D. and Lovegrove, W.: 1981, 'The effects of contrast, stimulus duration and spatial frequency of visible persistence in normal and specifically disabled readers', *Journal of Experimental Psychology: Human Perception and Performance* **7**, 495–505.

Breitmeyer, B. G.: 1983, 'Sensory masking, persistence, and enhancement in visual exploration and reading', in K. Rayner (ed.), *Eye Movements in Reading*, Academic Press, New York, pp. 3–30.

Breitmeyer, B. G. and Ganz, L.: 1976, 'Implication of sustained and transient channels for theories of visual pattern masking, saccadic suppression and information processing', *Psychological Review* **83**, 1–36.

Bryant, P. E. and Goswami, U.: 1987, 'Development of phonemic awareness', in J. Beech and A. Colley (eds.), *Cognitive Approaches to Reading*, John Wiley & Sons, Chichester, pp. 213–243.

Di Lollo, V., Hanson, D. and McIntire, J. S.: 1983, 'Initial stages of visual information processing in dyslexia', *Journal of Experimental Psychology: Human Perception and Performance* **9**, 923–935.

Ellis, N. C. and Miles, T. R.: 1981, 'A lexical encoding deficiency I: Experimental evidence', in G. Th. Pavlidis and T. R. Miles (eds.), *Dyslexia Research and Its Application to Education*, John Wiley & Sons, Chichester, pp. 177–215.

Hulme, C.: 1988, 'The implausibility of low-level visual deficits as a cause of children's reading difficulties', *Cognitive Neuropsychology* **5**, 369–374.

Kail, R.: 1991, 'Developmental change in speed of processing during childhood and adolescence', *Psychological Bulletin* **109**, 490–501.

Lovegrove, W., Martin, F. and Slaghuis, W.: 1986, 'A theoretical and experimental case for a visual deficit in specific reading disability', *Cognitive Neuropsychology* **2**, 225–267.

Martos, F. J. and Vila, J.: 1990, 'Difference in eye movements control among dyslexic, retarded readers and normal readers in the Spanish population', *Reading and Writing: An Interdisciplinary Journal* **2**, 175–188.

Pavlidis, G. Th.: 1985, 'Eye movements differences between dyslexics, normal and retarded readers while sequentially fixating digits', *American Journal of Optometry and Physiological Optics* **62**, 820–832.

Pavlidis, G. Th.: 1990, *Perspectives on Dyslexia. Vol. I. Neurology, Neuropsychology and Genetics*, John Wiley & Sons, Chichester.

Posner, M. and Mitchell, R.: 1967, 'Chronometric analysis of classification', *Psychological Review* **74**, 392–409.

Stanovich, K. E.: 1981, 'Individual differences in the cognitive processes of reading. II. Test level processes', *Journal of Learning Disabilities* **15**, 485–493.

D. LYNN FLOWERS

NEUROPSYCHOLOGICAL PROFILES OF PERSISTENT READING DISABILITY AND READING IMPROVEMENT

ABSTRACT. Adults diagnosed as either reading disabled, borderline, or good readers on the basis of childhood testing have been found to differ significantly on tests of phonological processing given in adulthood but not on tests on memory, attention, or visual perceptual skill. This suggest that phonological processing problems describe a core language deficit of reading disability. This paper examines the test score profiles of subjects categorized by their adult reading scores as well as by 'improvement', defined as upward movement from the disabled category after accounting for educational attainment and statistical regression.

These results generally support the hypothesis that there is an enduring phonological deficit in reading disability. However, post hoc examination of differences among reading levels reveals that 'improved' readers, while performing significantly better than the persistently impaired on many tests (including rapid naming with or without alternation of stimuli), perform no better than impaired readers on reading and manipulating non-words in spite of better reading achievement. Thus, it would appear that a better adult outcome is related to rapid, perhaps automatized, access to the phonetic code rather than to accurate phonological manipulation. This may be interpreted as improvement in spite of poor phoneme awareness, perhaps by way of available avenues of compensation. Such a distinction may provide a basis for subtyping the reading disabled as impaired in one or the other or both of these categories of language processing.

INTRODUCTION

Several studies have concluded that the reading disabled child and adult have a deficit involving phonological processes (see Rack *et al.*, 1992, for a review). For example, poorer performance on tasks of phoneme analysis and retrieval have been reported in reading disabled children (Catts, 1989; Denckla and Rudel, 1976; Felton and Brown, 1991; Felton and Wood, 1989; Felton *et al.*, 1987; Wagner and Torgesen, 1987; Wolf, 1984) as well as in reading disabled or illiterate adults (Bruck, 1990; Byrne and Ledez, 1983; Kitz and Tarver, 1989; Liberman *et al.*, 1985; Morais *et al.*, 1979).

In a recent investigation, Felton *et al.* (1990) studied 115 adults assigned by rather stringent criteria to RD, borderline, or good reading categories on the basis of childhood reading scores on two oral reading tests, the reading subtest of the Wide Range Achievement Test (WRAT; Jastak and Bijou, 1946) and the Gray Oral Reading Test (GORT; Gray, 1967). With IQ and SES differences statistically controlled, childhood reading level predicted adult measures of phoneme analysis and manipulation, rapid sequential retrieval of phonetic codes (recoding), and phonetic decoding

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of non-words. By contrast, childhood reading level did not predict adult performance on tasks of verbal or non-verbal memory, confrontational naming, verbal fluency, attentional control, or visual spatial judgement. It was concluded, therefore, that there is a phonological processing deficit which is basic and persistent in reading disability.

In a physiological study employing regional cerebral blood flow (Flowers *et al.*, 1991), using many of the same subjects (n = 83) examined by the Felton group, childhood reading level predicted activation at two left hemisphere regions believed to subserve language processing, both in the posterior peri-Sylvian region. Since statistically equating subjects for adult reading achievement did not affect the prediction of focal left hemisphere engagement from childhood reading level, this was considered further evidence of a persistent, language-based deficit. Further, these subjects' scores on phonological tests (phonemic manipulation and phonetic recoding) were positively correlated with activation of the left hemisphere Wernicke's area (Flowers *et al.*, under review).

Thus, there is converging evidence, both neuropsychological and physiological, of an enduring core language deficit. However, Felton and Brown (1990) have reported that in a sample of kindergarten children labeled at-risk for developmental reading disability, tests of phonological processing were not entirely intercorrelated after differences in intelligence were accounted for. Their results showed that rapid automatized naming (Denckla and Rudel, 1976), was not correlated with phoneme manipulation (Lindamood and Lindamood, 1971). In fact, only phonetic recoding predicted single word identification skill at the end of first grade testing. Thus, they proposed that phonological processes differentially, rather than uniformly, contribute to reading acquisition.

It is of interest, therefore, to consider whether there is a similar behavioral pattern discernable in adult subjects' neuropsychological test scores – even more so if we know the developmental history of the subjects. This can be done in a prospective study in which young children are followed throughout their reading development. Or, it can be done in a retrospective study if the early history is well documented. The ongoing investigations in this laboratory use both methods. The prospective study is still in its early stages and its progress has been reported (Brown and Felton, 1990; Felton, 1994; Felton and Brown, 1990, 1991; Felton and Wood, 1992). The present study utilizes the retrospective method by which impaired and unimpaired adult readers are compared, not only on the basis of their current reading level but also on the basis of higher than predicted reading achievement.

Accordingly, we gathered extensive detailed data from a large number of adult subjects whose reading skills had been evaluated in childhood at the Orton Reading Center (Winston-Salem, North Carolina) during its operation between 1957 and 1972. It was proposed that the same behavioral measures which distinguished adult impaired readers who had been categorized by childhood reading levels would distinguish them when categorized by adult reading levels. If some of these distinguishing tests in turn were found to characterize reading improvement, subtypes of reading disability would be suggested. Specifically, the following relationships were predicted:

1. As defined by two measures of adult reading ability, impaired readers will perform more poorly on phonological tests as compared with good readers but will not differ on other tests (i.e., memory, attention, and visual spatial skills).
2. Phonological manipulation and phonological recoding tasks will differentially predict outcome. Inasmuch as rapid naming tasks were shown in earlier studies to predict word identification, they are predicted to be related to improved reading in adults. Phoneme manipulation tasks, frequently shown to remain impaired into adulthood, are not expected to be related to improved reading.
3. The two types of phonological tasks – of manipulation and recoding – will be uncorrelated.

METHODS

Subjects

Subjects were 100 adults recruited from the archives of the Orton Reading Center (Winston-Salem, North Carolina) under the direction of June L. Orton between 1957 and 1972. These files, now stored at Columbia University in New York City, contain IQ and test scores and interview materials, ample documentation upon which to evaluate childhood reading skill as well as to rule out contraindicators. Files were accessed only with a subject's permission.

Subjects were included in the analysis whose childhood and adult scores were at least 80 on either the verbal or performance scale of the appropriate Wechsler IQ test (Wechsler, 1949 and 1981). Exclusion criteria were history of neurological or sensory impairment or major psychopathology.

Mean age and educational level at the time of adult testing were 33.7 years (S.D. = 5.2) and 14.7 years (S.D. = 2.5), respectively. Demographic and IQ characteristics are summarized by adult reading level in Table 1. Groups were found to differ significantly (by individual univariate analyses) on educational attainment, socioeconomic status, and intelligence scores but not on age at the time of testing. A significance level of $p < 0.05$ was accepted to reject the null hypothesis, adjusted for repeated

TABLE 1

Mean (standard deviation) demographic and intelligence characteristics of Orton Subjects by adult reading level (RD = reading disabled; BL = borderline; NRD = not reading disabled; SES = socioeconomic scale, Hollingshead, 1975).

	RD (n = 17)	BL (n = 35)	NRD (n = 48)
Age	33.5 (6.6)	33.6 (4.0)	32.9 (5.2)
Education[a]	13.8 (2.9)	15.1 (2.1)	16.9 (1.9)
Childhood IQ:			
Full Scale[b]	99.8 (12.3)	104.2 (11.4)	115.7 (9.3)
Verbal[a]	95.1 (12.3)	102.7 (12.3)	115.1 (9.4)
Performance[c]	105.4 (12.8)	106.0 (10.6)	113.9 (12.3)
Adult IQ:			
Full Scale[b]	95.3 (9.5)	96.3 (9.8)	110.5 (10.0)
Verbal[b]	91.7 (8.8)	96.4 (9.3)	108.8 (10.0)
Performance[b]	99.8 (12.3)	97.8 (11.0)	110.3 (11.5)
SES-Childhood[d]	45.2 (15.9)	51.3 (11.1)	57.2 (8.8)
SES-Adulthood[b]	40.9 (11.0)	44.7 (10.0)	51.6 (10.1)

[a] All paired comparisons significantly different ($p < 0.05$).
[b] RD and BL groups significantly below NRD group ($p < 0.005$).
[c] RD and BL groups significantly below NRD group ($p < 0.05$).
[d] RD and NRD groups differ ($p < 0.0005$).

between-group comparisons. A complete neuropsychological test battery was administered to adult subjects, recruited from the Orton archives. It included tests of IQ, oral reading, verbal and non-verbal delayed memory, visual spatial perception and judgement, and attentional control (described in detail below).

For the first analysis, based on adult testing, adult reading level was assigned on the basis of scores from both the Wide Range Achievement Test reading subtest (WRAT-R; Jastak and Wilkinson, 1984) and the Gray Oral Reading Test (GORT; Gray, 1967). Cut scores were $\leqq 82$ (the lower 12%) for disabled readers and $\geqq 92$ (above the 20th percentile) for non-disabled readers on the WRAT-R. GORT cut scores were standardized values based on a deviation formula (Finucci *et al.*, 1984) which reflects the discrepancy between actual and predicted reading scores after gender and IQ are considered. The cut scores suggested by Finucci *et al.* (1984) of -2.00 and -1.00 were adopted. The good reading group was limited to subjects falling within the age, education, and IQ range of the stan-

TABLE 2

Mean scores (standard deviations) for neuropsychological test battery by adult reading classification. Variables are defined in the text.

Adult Tasks	RD (n = 17)	BL (n = 35)	NRD (n = 48)
RAN[a]	34.0 (7.3)	28.3 (3.6)	25.9 (3.6)
RAS[a]	33.3 (9.1)	25.7 (5.1)	23.2 (5.2)
LAC[b]	68.3 (14.0)	75.9 (12.5)	92.2 (8.6)
WORD ATTACK[b]	11.6 (4.7)	14.9 (3.9)	19.8 (3.3)
BNT	53.8 (4.7)	53.9 (3.1)	56.6 (3.0)
FAS	34.3 (11.1)	34.0 (11.0)	44.5 (10.8)
JL	27.8 (4.8)	25.4 (3.7)	28.2 (2.2)
TRAILS B	91.8 (23.8)	80.5 (22.7)	65.4 (20.6)
PROSE RECALL	11.9 (3.4)	10.9 (4.0)	13.4 (3.7)
AVLT BEST	10.5 (3.3)	11.7 (2.2)	12.9 (1.6)
AVLT RECALL	9.3 (2.4)	10.0 (2.5)	11.1 (2.7)
CFT COPY	33.5 (2.7)	33.8 (2.1)	34.8 (1.8)
CFT RECALL	27.9 (5.6)	26.4 (4.4)	29.0 (4.0)

[a] RD group significantly slower than either the RD or the BL groups ($p < 0.0001$).

[b] All comparisons significant (RD versus BL groups, $p < 0.05$; RD versus NRD groups, $p < 0.001$; BL versus NRD groups $p < 0.01$).

dardization reference group (described below). These criteria yielded a reading disabled (RD) group of 17, a borderline (BL) group of 35, and a non-disabled (NRD) group of 48. Means and standard deviations for the neuropsychological test scores are given by reading level in Table 2.

For the second analysis, adult outcome was based on adult reading scores given childhood reading level. Childhood reading level was also assigned on the basis of two oral reading scores as recorded in the childhood files, the WRAT (Jastak and Bijou, 1946) and the GORT (Gray, 1955). Childhood RD subjects were said to be those whose reading quotients (reading age/chronological age times 100; Boder and Jarrico, 1982) were 82 or below for both reading measures. This cutoff score was chosen to be a one and one-half year reading age lag at the beginning of the third grade. Subjects whose quotients on both tests were 92 or above were classified as not reading disabled (NRD). All others were labeled borderline (BL).

Persistent reading disability (PRD), reading improvement (IRD), and never impaired (NI) groups were chosen by comparing subjects' child and

TABLE 3

Mean (S.D.) demographic and intelligence characteristics of Orton Subjects by adult outcome reading level (PRD = persistently reading disabled; IRD = improved reading disabled; NI = never impaired; SES = socioeconomic scale, Hollingshead, 1975).

	PRD (n = 17)	IRD (n = 18)	NI (n = 46)
Age	33.8 (6.4)	33.7 (4.5)	33.0 (5.1)
Education[a]	13.8 (2.9)	14.7 (2.1)	16.9 (1.9)
Childhood IQ:[a]			
Full Scale	99.8 (12.3)	101.2 (9.4)	116.0 (9.3)
Verbal	95.1 (12.3)	99.1 (10.3)	115.5 (9.5)
Performance	105.4 (12.8)	103.4 (9.7)	114.2 (12.3)
Adult IQ[a]			
Full Scale	94.3 (9.5)	95.3 (10.4)	110.8 (9.9)
Verbal	91.7 (8.8)	95.2 (10.6)	109.0 (9.9)
Performance	99.8 (12.6)	97.3 (10.6)	110.6 (11.6)
SES-Childhood[b]	45.2 (15.9)	51.1 (11.2)	57.0 (8.9)
SES-Adulthood[b]	40.9 (11.0)	44.1 (10.6)	51.9 (10.2)

[a] PRD group differs significantly from the IRD and NI groups ($p < 0.0001$).

[b] NI group differs significantly from the PRD and IRD groups ($p < 0.01$).

[c] PRD group significantly lower than the NI group ($p < 0.005$).

adult categories. An RD child who moved to the BL or NRD category (53%) was said to improve. Subjects who were never impaired were those who had a childhood classification of NRD and would not be considered either disabled or borderline as adults by the above criteria. Thus, childhood BL subjects were not included in this analysis and the sample size was reduced from the original 100 to 81 (PRD = 17, IRD = 18, and NI = 46).

The shortcomings of this definition are recognized. A preferable basis for judgement would be comparable raw scores for both criteria tests; however, in most cases, the childhood archive contained only grade equivalents. Conversely, reading quotients based on grade equivalent score and chronological age are relatively meaningless for adults.

Tables 3 and 4 give the demographic and achievement score information summarized by adult reading outcome (changing or staying the same from childhood to adult). Univariate statistics failed to show significant

TABLE 4

Comparison of mean scores (standard deviations) on neuropsychological test battery for persistently reading disabled (PRD) and improved (IRD) adults classified as reading disabled in childhood. Tests are described in detail in text. Significance levels are for paired comparisons after controlling for statistical regression and educational attainment.

Test	PRD (n = 17)	IRD (n = 18)	NI (n = 46)
RAN (time)[a]	34.0 (7.3)	29.5 (3.8)	25.7 (3.6)
RAS (time)[a]	33.3 (9.1)	27.4 (5.7)	22.9 (5.0)
LAC[b]	68.3 (14.0)	75.8 (14.2)	92.2 (8.6)
WORD ATTACK[b]	11.6 (4.7)	13.3 (4.1)	20.1 (2.9)
BNT	53.8 (4.7)	54.1 (3.5)	56.7 (2.9)
FAS	34.3 (11.1)	36.7 (11.1)	44.3 (10.9)
JL	27.8 (4.8)	25.4 (4.1)	28.2 (2.2)
TRAILS B (time)	91.8 (23.8)	75.5 (20.3)	65.7 (21.0)
PROSE RECALL	11.9 (3.4)	10.0 (4.5)	13.3 (3.7)
AVLT BEST[c]	10.5 (3.3)	11.2 (2.1)	12.9 (1.6)
AVLT RECALL	9.3 (2.4)	9.2 (2.2)	11.1 (2.8)
CFT COPY	33.5 (2.7)	34.2 (1.7)	34.7 (1.8)
CFT RECALL	27.9 (4.8)	28.1 (4.0)	28.8 (4.0)

[a] PRD group significantly slower than either the IRD or NI groups ($p < 0.01$).

[b] NI group scored significantly higher than either the IRD or PRD groups ($p < 0.001$).

[c] PRD and IRD groups both have significantly lower scores than the NI group ($p < 0.001$).

differences between the PRD and IRD groups. However, both groups were significantly lower on all measures of intelligence, educational attainment, and socioeconomic status (SES) achieved in adulthood when compared to the NI group. Groups did not differ with respect to age or sex.

Adult Behavioral Evaluation

The following tests of word skill, memory, and attention were part of the cognitive battery. These were included in a multivariate analysis.

- Tests of phonetic recoding:
    - *Boston Naming Test* (Kaplan *et al.*, 1982) – a test of confrontation naming (BNT).

- *Rapid Automatized Naming Test* (Denckla and Rudel, 1976) – rapid retrieval of linguistic materials. The average latency for the naming of colors, objects, digits and letters was used (RAN).
- *Rapid Alternating Stimulus Test* (Wolf *et al.*, 1986) – rapid set shifting in naming an alternating series of numbers, letters and colors. An average latency for a 2-set and a 3-set series was used (RAS).

– Test of phonetic awareness:

- *Lindamood Auditory Conceptualization Test* (Lindamood and Lindamood, 1971) – a test of phonetic discrimination and analysis skills (LAC).

– Test on non-word reading:

- *Word Attack* subtest from the Woodcock–Johnson Psychoeducational Battery (Woodcock and Johnson, 1977) – a test of non-word reading (WORD ATTACK).

– Tests of memory, learning, attention, fluency and spatial judgement:

- *Prose Recall* (Talland, 1965) – delayed recall of an orally administered narrative passage (PROSE RECALL).
- *Rey Auditory Verbal Learning Test* (Rey, 1964) – learning and free recall of an unstructured word list, the best of five trials (AVLT BEST) and post-distractional memory (AVLT RECALL).
- *Complex Figure Test* (Rey, 1941 and Taylor, 1959) – raw scores for the copy (CFT COPY) and delayed recall (CFT RECALL).
- *Verbal Fluency Test* (Lezak, 1983) – a measure of linguistic word retrieval, the sum for recall of words beginning with 'F', 'A', or 'S' (FAS).
- *Trailmaking Test* (Army Individual Test Battery, 1944) – visuomotor tracking test requiring a rapid change of attentional set (TRAILS B).
- *Judgment of Line Orientation* (Benton *et al.* 1983) – a match-to-sample test of visual spatial judgement (JL).

Procedure

The cognitive test battery was administered under standardized conditions in either one or two sessions at the convenience of the subject. Some subjects also submitted to physiological measures, reported elsewhere (Flowers *et al.*, 1991; Flowers *et al.*, under review). All subjects received an honorarium for their participation.

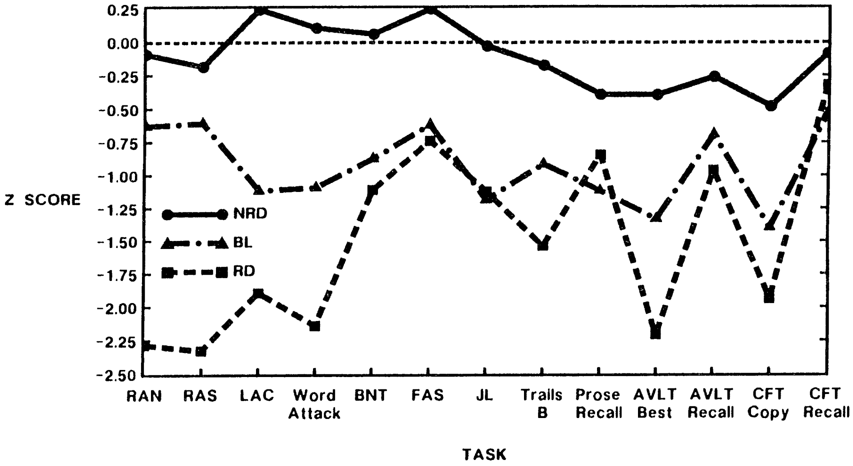

Fig. 1. Standardized scores on adult administered tests are plotted by adult reading level. Significantly lower scores on RAN and RAS are found in the reading disabled (RD) and borderline (BL) subjects as compared to those not reading disabled (NRD). RD subjects also score significantly lower than all other subjects on Word Attack and LAC. (See text for a list of tests.)

Statistical Analysis

Mean scores and standard deviations on the test battery given to 23 normal male subjects, with no evidence of early reading problems in their school records, served as the reference for standardizing scores on the 13 behavioral tests. A multivariate analysis tested differences across adult reading levels on the battery, and repeated measure analyses of covariance tested adult reading level effects on individual tasks. In both cases two scores of variance were controlled, IQ and educational achievement at the time of testing. Post hoc comparisons between groups were considered significant at $p < 0.05$, adjusted in accord with Holme's sequentially rejective multiple test procedure (Holme, 1979).

Relationships among tests were evaluated by a Pearson correlation with IQ and educational attainment partialled out.

RESULTS

Neuropsychological Profile by Adult Reading Diagnosis

The overall multivariate analysis revealed a significant difference between adult reading level and neuropsychological measures ($p = 0.0295$, Wilks' Lambda statistics). Figure 1 shows this relationship by individual standard-

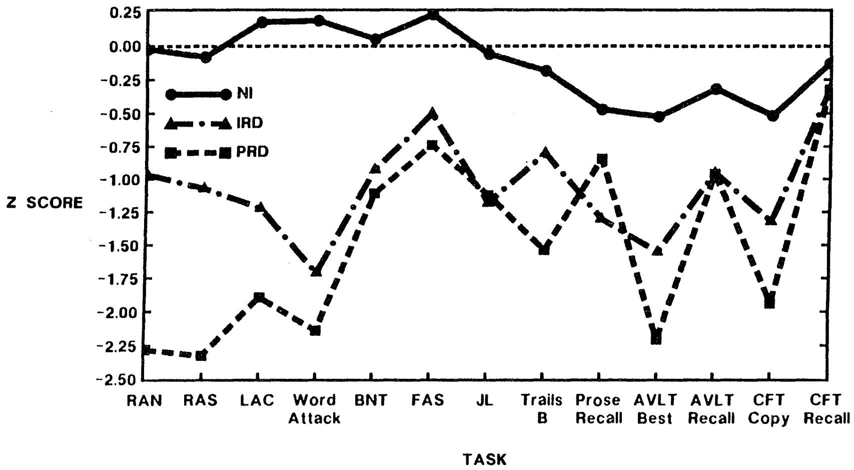

Fig. 2. Standardized scores on adult administered tests are plotted by improvement in reading from childhood to adult outcome reading level. Those who were reading disabled as children have been separated into persistent reading disabled (PRD) and improved reading disabled (IRD) adult groups. PRD and IRD subjects still perform significantly worse than the never impaired (NI) subjects on Word Attack and LAC. However, the improved subjects are indistinguishable from subjects who were never impaired on RAN and RAS. (See text for list of tests.)

ized test scores compared with a normal reference group. Paired comparisons, where separate univariate analyses were significant, revealed lower standardized scores (i.e., slower speeds) for the adult RD and BL groups on tests of phoneme recoding (RAN and RAS; $p < 0.001$), and lower scores for RD subjects on non-word reading (WORD ATTACK) and phoneme analysis and manipulation (LAC; $p < 0.001$). Tests of verbal learning and memory, visual spatial perception and judgement, and attention, however, failed to distinguish among groups.

Neuropsychological Profile by Adult Outcome Group

The overall multivariate analysis also revealed significant differences ($p = 0.0406$, Wilks' Lambda statistic) on this neuropsychological test battery by adult outcome reading. The profiles of standardized scores by reading outcome are shown in Figure 2. Where the univariate analyses were significant, RAN, RAS, LAC, and WORD ATTACK, paired comparisons were carried out. Tests of recoding (rapid sequential naming) were performed significantly better by both the IRD and NI groups as compared to the PRD group ($p < 0.01$). However, tests of non-word reading and phoneme manipulation were performed equally by the PRD and IRD groups, both of which differed from the NI group.

As an additional precaution against missing other sources of influence on adult outcome skills (Satz *et al.*, 1978), both of the above studies were re-analyzed in different ways. First, childhood socioeconomic status (SES) was added to the multivariate and univariate analyses. Although there were minor differences in significance levels, the addition of SES did not change the results already described. That is, univariate statistics showed that it is the phonetic awareness tests (Lindamood and Woodcock–Johnson Word Attack), and phonetic recoding (rapid naming) on which adult RD subjects perform more poorly. Measures of verbal learning, attention, and spatial skills do not differ statistically across reading levels.

Two analyses looked only at those with a childhood diagnosis of RD. First, in order to account for changes due to statistical regression, subjects were divided into two groups by WRAT and GORT standardized residual scores (childhood WRAT reading quotient predicting adulthood standard WRAT score and childhood GORT reading quotient predicting adulthood GORT raw score). Those with better than predicted outcome scores on both tests (above 0) and those with worse than predicted scores (below 0) defined the two outcome groups. WISC verbal IQ was controlled in separate analyses of covariance predicting test scores. As before, only tests of phonetic recoding significantly predicted improved reading in those subjects previously diagnosed as RD on the basis of childhood data.

Finally, because there was a small but significant difference between the improved and persistent groups on childhood reading scores, the groups were matched for WRAT and GORT childhood scores. This necessitated dropping five subjects from the persistent (PRD) group ($n = 12$). Again, the same effects were found although significance levels for the two phonetic recoding tasks of interest (RAN and RAS) were reduced from $p < 0.01$ to $p < 0.05$. Even though the univariate test for group differences on the Trail B attentional task was not significant, by paired comparisons the persistent group performed significantly more poorly ($p < 0.05$) than did the improved group.

Correlation between Measures of Adult Reading and Phonological Tasks

Table 5 shows the partial correlation between phonological task scores, verbal memory, and attention and two separate measures of adult oral reading (the WRAT reading subtest and the GORT), with WAIS and educational attainment removed. The hypothesis that RAN and RAS scores would be uncorrelated with WORD ATTACK was confirmed: no measures of phonological skills were significantly correlated. However, although only RAN and RAS predicted paragraph reading, those scores as well as WORD ATTACK and LAC scores predicted single word (WRAT-R) reading.

TABLE 5

Pearson r values for correlation (IQ and education partialled out) between reading measures, phonetic skills, and attention in n = 36 subjects diagnosed in childhood, approximately half of whom improved.

	RAN	RAS	LAC	WORD ATTACK	TRAILS B
WRAT Reading	0.35^a	0.42^a	0.35^a	0.34^a	0.29
GORT Reading	0.59^b	0.58^b	0.17	0.19	0.43^a
RAN	–	0.86^c	0.29	0.22	0.31
RAS	–	–	0.29	0.26	0.34
LAC	–	–	–	0.32	0.30
WORD ATTACK	–	–	–	–	0.09

[a] $p < 0.05$
[b] $p < 0.0005$
[c] $p < 0.0001$

The attentional measure was moderately correlated with paragraph reading only.

COMMENT

Previous analyses of adult neuropsychological profiles had shown that tests of specific language skills requiring phonological manipulation and phonetic recoding could be predicted from known childhood reading ability. This suggested a persisting deficit associated with reading disability. Another adult study suggested an enduring left hemisphere substrate for these processes. However, among young children at risk for developmental RD, tests of phonological manipulation and phonetic recoding in lexical access were not found to be correlated with each other, and they differentially predicted reading achievement measures at the end of first grade. The purpose of this paper was to investigate whether there were enduring, phonologically-based or other skills associated with adult reading ability *per se* as well as with reading improvement. It was proposed that measures of phonetic awareness and phonetic recoding would differentially predict adult outcome and that such could be the basis for subtypes of RD.

As predicted, those defined as impaired by adult reading measures remain poor on phonological tasks. This finding is also in agreement with the earlier report by Felton *et al.* (1990) which also found differences only on the phonological measures when childhood reading was the basis for reading level assignment. By adult diagnosis, a large number (51%) of those who where impaired in childhood improved to either borderline or good reading status leaving only the 'hard core' subjects in the disabled group. The small but significant attentional distinction between the persistently impaired and the improved was not predicted and should, therefore, be regarded cautiously. It is interesting, however, that the attentional test score is moderately related to Gray oral reading, perhaps suggesting the wisdom of accounting for attentional deficits in these subjects – or, perhaps due to the fact that the tests have in common that they are timed. Or, it may be that the more severely disabled readers are more likely to exhibit other types of impairment.

Also as predicted, the 'improved' readers as a group were not more skilled than those who remained impaired on measures of phoneme awareness (auditory phoneme conceptualization and manipulation and non-word reading). The improved readers, however, were distinguished from the persistently impaired by faster overall speed in retrieving strings of labels either by single categories or when alternating among categories.

It appears from these data that although some tasks are performed better by improved readers, others are resistant to change over time. Were the improved reading disabled subjects merely developmentally slow children who eventually caught up? Arguably not, since substantial reading improvement would then have occurred rather than the modest improvement actually observed. Furthermore, the residual phonemic awareness deficits in improved subjects argues against a 'catch up' explanation. In accord with reading-age match studies (Felton and Wood, 1992), these results would seem to show that actual reading skills as measured here exceed predictions from certain of the subjects' phonological skills – those which rely on deciphering unfamiliar, particularly irregular words. Conversely, those which require the rapid retrieval of stored lexical code are directly associated with better adult than childhood reading level.

These results also support the proposition that phonetic recoding and phonetic manipulation are separable functions which contribute differentially to some reading measures. However, while phonetic manipulation skills do not predict paragraph reading, they do predict single word reading when it is considered separately. Thus, a prediction of reading skill on the basis of single word reading alone would lead to the conclusion that both phonetic manipulation and phonetic recoding contribute linearly to oral single word reading while only fluent phonetic recoding contributes to oral paragraph reading, at least under timed conditions. Perhaps the variance shared between the Gray oral reading score and phonetic recoding scores is the imposed time constraint. (In both tests, subjects are instructed to do the task as quickly as possible without sacrificing accuracy.)

In general terms, a better adult outcome score may be said to depend to a high degree on automatization of phonological codes, i.e., accurate, rapid retrieval of phonological codes is an advantage. Possibly, demonstrated remediation of reading disability occurs in the face of persisting core deficits because overpractice of essential phonological skills results in more highly automatized phonological retrieval (Bradley and Bryant, 1983; Felton, 1994). If so, the advantage may more readily be observed when time constraints are imposed. In other words, a timed test is perhaps a more sensitive measure of efficient, especially fluent, reading.

In accord with this, Decker (1989) found naming speed and rapid recognition of pronounceable non-words to be the best discriminators of reading disability in adults. Likewise, rapid naming measured in the first grade has been reported to predict early reading achievement (Wolf *et al.*, 1986). This information could be useful for predicting outcome from an early age and planning remediation accordingly.

It has been suggested elsewhere (Felton, 1994) that children learning to read can have either a problem with phonological manipulation, a problem with phonological recoding, or both. These results corroborate the independence of these skills in an adult sample and as such provide a basis for subtyping. Whether pure examples of each exist has not been addressed by these analyses. However, the group data do suggest that the most severely and persistently impaired readers have a phonological manipulation problem as well as a recoding problem while those with a better outcome are able to access more rapidly the lexical code. Further, the persistently impaired may have other tangential problems, such as attentional inefficiencies, which contribute to an overall poorer performance. Improvement, as defined here, may not just depend on the ability to access the lexical code efficiently – 'improvement' may *be* that ability.

If, as stage models suggest, phonological skills are necessary for the acquisition of lexical code the dyslexic is disadvantaged by poor phonological skills. Nevertheless, all is not lost. Even severely disabled individuals usually possess at least a modicum of phonological ability. Thus, as has been shown (Felton and Brown, 1990), they can develop a sight word vocabulary comparable to that of their peers when aided by teaching materials and methods which emphasize phonics, at least when instruction begins early. Pennington *et al.* (1987) have presented evidence that the development of phonological skills probably extends into adulthood for both RD and non-RD readers. Therefore, it seems likely that not only methods and materials but persistence is a contributing factor to reading outcome.

These results should serve as a caution to researchers using adult populations to study reading or language processes. That is, the assignment of subjects to a non-impaired comparison group on the basis of adult reading scores alone could surreptitiously allow the inclusion of remediated RDs. These data suggest that adult subjects with poor scores on tests of phonetic awareness should not be considered normal for studies of language processing or reading regardless of their reading or naming skills as measured in adulthood.

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REFERENCES

Army Individual Test Battery, Manual of Directions and Scoring: 1944, War Department, Adjutant General's Office, Washington, DC.

Benton, A. L., Hamsher, K. de S., Varney, N. R. and Spreen, O.: 1983, *Contributions to Neuropsychological Assessment*, Oxford University Press, New York.

Boder, E. and Jarrico, S.: 1982, *The Boder Test of Reading-Spelling Patterns: A Diagnostic Screening Test for Subtypes of Reading Disability*, Grune and Stratton, New York.

Bradley, L. and Bryant, P. E.: 1983, 'Categorizing sounds and learning to read: A causal connection', *Nature* **301**, 419–421.

Brown, I. S. and Felton, R. H.: 1990, 'Effects of instruction of beginning reading skills in children at risk for reading disability', *Reading and Writing: An Interdisciplinary Journal* **2**, 223–241.

Bruck, M.: 1990, 'Word recognition skills of adults with childhood diagnoses of dyslexia', *Developmental Psychology* **266**, 439–454.

Byrne, B. and Ledez, J.: 1983, 'Phonological awareness in reading-disabled children', *Australian Journal of Psychology* **35**, 185–197.

Catts, H. W.: 1989, 'Phonological processing deficits and reading disabilities', in S. Kamhi and H. Catts (eds.), *Reading Disabilities: A Developmental Perspective*, College-Hill Press, Boston, pp. 101–132.

Decker, S.: 1989, 'Cognitive processing rates among disabled and normal reading young adults: A nine year follow-up study', *Reading and Writing: An Interdisciplinary Journal* **2**, 123–134.

Denckla, M. A. and Rudel, R. G.: 1976, 'Naming of object drawings by dyslexic and other learning disabled children', *Brain and Language* **3**, 1–16.

Felton, R. H.: 1993, 'Impact of instruction on word identification skills in children with phonological processing problems', in R. M. Joshi and C. K. Leong (eds.), *Reading Disabilities: Diagnosis and Component Processes*, Kluwer Academic Publishes, Dordrecht, pp. 267–278.

Felton, R. H. and Brown, I. S.: 1990, 'Phonological processes as predictors of specific reading skills in children at risk for reading failure', *Reading and Writing: An Interdisciplinary Journal* **2**, 39–59.

Felton, R. H. and Brown, I. S.: 1991, 'Neuropsychological prediction of reading disabilities', in J. E. Obrzut and G. W. Hynd (eds.), *Neuropsychological Foundations of Learning Disabilities: A Handbook of Issues, Methods, and Practice*, Academic Press, New York, pp. 387–410.

Felton, R. H., Naylor, C. E. and Wood, F. B.: 1990, 'The neuropsychological profile of adult dyslexics', *Brain and Language* **39**, 485–497.

Felton, R. H. and Wood, F. B.: 1989, 'Cognitive deficits in reading disability and attention deficit disorder', *Journal of Learning Disabilities* **22**, 3–13.

Felton, R. H. and Wood, F. B.: 1992, 'A reading level match study of nonword reading skills in poor readers with varying IQ', ıJournal of Learning Disabilities **25**, 318–326.

Felton, R. H., Wood, F. B., Brown, I. S., Campbell, S. K. and Harter, M. R.: 1987, 'Separate verbal memory and naming deficits in attention deficit disorder and reading disability', *Brain and Language* **31**, 171–184.

Finucci, J. M., Whitehouse, C. C., Isaccs, S. D. and Childs, B.: 1984, 'Derivation of validation of a quantitative definition of specific reading disability for adults', *Developmental Medicine and Child Neurology* **26**, 143–153.

Flowers, D. L., Wood, F. B. and Naylor, C. E.: 'Regional cerebral blood flow correlates and the adult dyslexic phenotype' (under review).

Flowers, D. L., Wood, F. B. and Naylor, C. E.: 1991, 'Regional cerebral blood flow correlates of language processes in reading disability', *Archives of Neurology* **48**, 637–643.

Gray, W. S.: 1955, *Standardized Oral Reading Paragraphs*, Bobbs-Merrill, Indianapolis.

Gray, W. S.: 1967, *Gray Oral Reading Tests*, Pro-Ed, Austin, TX.

Holme, S.: 1979, 'A simple sequentially rejective multiple test procedure', *Scandinavian Journal of Statistics* **6**, 65–70.

Jastak, J. and Bijou, S.: 1946, *Wide Range Achievement Test*, Jastak Associates, Wilmington.

Jastak, J. and Wilkinson, G. S.: 1984, *Wide Range Achievement Test: Revised Edition*, Jastak Associates, Wilmington.

Kaplan, E., Goodglass, H. and Weintraub, S.: 1982, *Boston Naming Test*, Lea & Febiger, Philadelphia.

Kitz, W. R. and Tarver, S. G.: 1989, 'Comparison of dyslexic and nondyslexic adults on decoding and phonemic awareness tasks', *Annals of Dyslexia* **39**, 196–205.

Lezak, M. D.: 1983, *Neuropsychological Assessment*, Oxford University Press, New York/Oxford.

Liberman, I. Y., Rubin, H., Duques, S. and Carlisle, J.: 1985, 'Linguistic abilities and spelling proficiency in kindergarteners and adult poor spellers', in D. B. Gray and J. F. Kavanaugh (eds.), *Biobehavioral Measures of Dyslexia*, York Press, Parkton, MD, pp. 163–176.

Lindamood, C. H. and Lindamood, P. C.: 1971, *Lindamood Auditory Conceptualization Test*, Teaching Resources Corporation, Boston.

Morais, J., Cary, L. Algeria, J. and Bertleston, P.: 1979, 'Does awareness of speech as a sequence of phones arise spontaneously?', *Cognition* **7**, 323–331.

Pennington, B. F., Lefly, D. L., Van Orden, G. C., Bookman, M. O. and Smith, S. D.: 1987, 'Is phonology bypassed in normal and dyslexic development', *Annals of Dyslexia* **37**, 62–89.

Rack, J. P., Snowling, M. J. and Olson, R. K.: 1992, 'The nonword reading deficit in developmental dyslexia: A review', *Reading Research Quarterly* **27**, 28–53.

Rey, A.: 1941, 'L'examen psychologique dans les cas d'ence-phlalopathie traumatique', *Archives de Psychologie* **28**(112), 286–340.

Rey, A.: 1964, *L'Examen Clinique en Psychologique*, Presse Universitaires de France, Paris.

Satz, P., Taylor, G. H., Friel, J. and Fletcher, J. M.: 1978, 'Some developmental and predictive precursors of reading disabilities: A six year follow-up', in A. L. Benton and D. Pearl (eds.), *Dyslexia: An Appraisal of Current Knowledge*, Oxford University Press, New York, pp. 315–347.

Talland, G. A.: 1965, *Deranged Memory*, Academic Press, New York.

Taylor, E. M.: 1959, *The Appraisal of Children with Cerebral Deficits*, Harvard University Press, Cambridge, MA.

Wagner, R. K. and Torgesen, J. K.: 1987, 'The nature of phonological processing and its causal role in the acquisition of reading skills', *Psychological Bulletin* **101**, 192–212.

Wechsler, D.: 1949, *Manual for the Wechsler Intelligence Scale for Children*, Psychological Corp., New York.

Wechsler, D.: 1981, *Manual for the Wechsler Adult Intelligence Scale – Revised*, Psychological Corp., New York.

Wolf, M.: 1984, 'Naming, reading, and the dyslexias: A longitudinal overview', *Annals of Dyslexia* **34**, 34–115.

Wolf, M., Bally, H. and Morris, R.: 1986, 'Automaticity, retrieval, processes, and reading: A longitudinal study in average and impaired readers', *Child Development* **57**, 988–1000.

Wood, F.: 1980, 'Theoretical, methodological, and statistical implications of the inhalation of rCBF technique for the study of brain-behavior relationships', *Brain and Language* **9**, 1–8.

Woodcock, R. W. and Johnson, M. G.: 1977, *Woodcock–Johnson Psycho-Educational Battery*, Teaching Resources, Hingham, MA.

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INFLUENCE OF LITERACY (VS ILLITERACY) ON THE CHARACTERISTICS OF ACQUIRED APHASIA IN ADULTS

ABSTRACT. The study of illiterate subjects with brain lesions is a good model to understand the cultural variable for cerebral functional organization. The question of aphasia in this population is reviewed in this chapter. There are problems concerned with the test material used, which has to be adapted for illiterate subjects: visual naming, for instance, has to be tested with real objects and not with line drawings of the objects. However, when aphasia is considered there are not important differences, between illiterate and literate subjects, on what concerns the cardinal symptoms which allow a clinical diagnosis of aphasia type. Some non-verbal defects, like constructional apraxia, may, however, reflect differences.

INTRODUCTION

One of the interesting topics for investigation in the area of Brain/Behavior relationships concerns the understanding of the influence of the information content and its organizational rules on the structural organization of the brain. It is well accepted that to deal with each behavioral skill there is a biological structure that distributes in networks within the brain in a relatively constant fashion in individuals matched for cultural background. This distribution is based both on the biological potential of the existing networks and on the specificity of the information and of the strategies used to solve problems related to that information.

The rules for linguistic processing are thought to be universal in humans and the brain areas involved seem to be the same in the majority of the speakers. There are recognized exceptions like, for instance, crossed aphasia but these are, most probably, related to biological variants and not the result of 'external' influences (for general reference, see Castro-Caldas, 1991). Nevertheless, some cross linguistic studies of aphasia suggest that there may be differences according to the characteristics of the language used (see, for instance, *Brain and Language* **41** (2), August 1991).

Illiteracy is a possible model to study this problem. The correct use of oral language without its written counterpart may stem from particular arrangements of brain structure. Phonologic awareness is different, visual systems never interfere in language processing and there is no influence of space processing systems which are involved in visual scanning and in handwriting.

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It is, however, important to stress that in the early XIX century, when the scientific basis for research in the field of brain and language was found, literacy was an exceptional aptitude reserved for the few of the higher social classes. Necropsy studies were performed mostly in indigent people and yet it was possible for the pioneers to find a correlation between language and the left hemisphere.

In recent years due to the progressive sophistication of language analysis in aphasia, interest was shown in this population that fortunately tends to be a minority in developed countries.

In Portugal, social development was slow compared with the other countries in Europe and illiteracy is a common finding in the rural population now in their sixties. In the last census of the population (1991) 13% of the inhabitants were classified as illiterates. This means that there are more than a million in the country.

It is important to define this population before describing our findings. These are mostly women that were educated to work on the fields, to take care of the house, and to have children. They started working very early in life, as soon as they could walk and carry objects. The pressure for survival with poor resources prevented their parents to send them to school. They grew up in the fields in close connection with agriculture and did their job fairly well according to the tradition. They learned how and when to seed; they learned how to build houses; they learned how to take care of animals; they learned how to conduct business in the market and they learned sophisticated ways of collecting non-written information. They never learned how to use a pencil to draw in two dimensions; they never learned how to code phonemic information into written symbols. They do practise abstract thinking and deal reasonably well with logical rules that subserve arithmetic and problem solving. Sometimes they use very subtle and imaginative ways to perform simple arithmetical operations.

In general, it is possible to define this population as having a normal potential for dealing with problems but that received a different kind of information. The final product is difficult to assess using current sophisticated psychological tests. Their performance on the WAIS is, for instance, scored to the level of deep retarded and yet they perform in life quite accurately and successively according to their standards.

THEORETICAL ISSUES

Theoretical issues that can be raised when studying such a population can be enumerated as follows.

1. Is it possible that the exposure of normal brain to different information carries a peculiar arrangement of brain/function relation? This

question can be divided into two different problems: (a) Does the different information constitute a trigger for the development of particular brain/function structures?, and (b) How is a function, like oral language, organized in the brain of these particular population in terms of areas involved in its processing?
2. Is the aphasia type distribution similar in illiterates as compared with the one of literate people?
3. Is the aphasia as severe in illiterates as in literate persons?
4. Is aphasia as persistent (and similarly sensitive to speech therapy) in illiterates compared to literate?
5. Are there peculiarities in aphasia utterances in illiterates (naming, repetition)?
6. Is there any difference in the severity and frequency of non-verbal dysfunction accompanying aphasia in illiterates?
7. Is it possible to identify new signs of dysfunction related exclusively to this population?

It is difficult, for the time being, to identify functions or strategies that are exclusive of the illiterate population. The absence of general programs of teaching cognitive strategies results in the emergence of individual skills that differ from subject to subject. The only observation that seems to be important to report is that non-brain-lesioned poor acculturated subjects while performing a task of three-dimensional construction, tend to be more talkative than the acculturated ones. For instance, they commonly accompany their execution by saying "this is a long piece ... where is it ... this must be similar ... I have to put it over this small one ...". This behavior is probably important for the findings we reported that constructional apraxia is more frequent in illiterate aphasics as compared with literate ones. We will discuss this topic later in this chapter.

The impossibility of identifying peculiarities makes it impossible to find signs of dysfunction exclusive of this population. Most probably non-verbal capabilities are differently developed but we failed until now to find good tools to assess these differences.

EXPERIMENTAL STUDIES

There is some experimental work reported in the literature comparing performances of differently educated populations in several tests. Ostrosky *et al.* (1985, 1986) gave a neuropsychological diagnostic battery to 109 normal subjects from two sociocultural levels and found that the items more sensitive to this variable were those that involved the use of complex conceptual aspects of language and the organization of motor sequences and motor programs in general.

André Roch Lecours (Lecours *et al.*, 1987a, 1987b, 1988) reviewed extensively the literature concerning aphasia in illiterates. Personal opinions and anecdotal evidence constitute the first chapter of this story. Most of those authors suggested that either aphasia tended to be less severe and more transient in illiterate persons or that language tended to be localized on the right hemisphere. A common opinion was for instance that crossed aphasia was more prevalent among illiterates. There is strong evidence showing that the biological base for brain functional asymmetry is genetically determined. Hemispheric asymmetries were found in adults (Geschwind and Levitsky, 1968) in fetal brains (Teszner *et al.*, 1972) and yet suspected in skulls of the primitive man. Thus, it is language that occupies the structures that are adapted for its development and there are no reasons to think that functional lateralization should be dependent on learning, or not, a specific kill. A different problem concerns, perhaps, the late acquisition of a skill, i.e., if one learns late in life how to read and to write it is possible that the brain is no longer prepared to receive the information the same way it receives it in the proper moment. But this is a different problem, as it happened with language in the case of Genie (Curtiss, 1977).

On the other hand, we have been interested in Crossed Aphasia and in our series this is a finding as rare in illiterate as in literate people.

We can thus conclude that there are no theoretical reasons to suspect that hemispheric dominance for language is different in illiterate subjects. We can, however, hypothesize that some of the non-linguistic components of oral communication, like prosody, for instance, are more important for these subjects' communication. Being so, maybe the right hemisphere plays a more important role in illiterates' communication.

Nevertheless, Cameron and co-workers published in 1971 a report reviewing the cases of 62 right-handed and 3 left-handed adults with right hemiparesis or hemiplegia resulting from a left sylvian stroke. Thirty-seven subjects were said to be literate, 14 semi-literate and 14 illiterate. They found transitory or persistent aphasia in 78% of the literates, 64% of the semi-literates and 36% of the illiterates. It is, however, important to note that the group that these authors considered illiterate had an average of 2.5 years of schooling. We can always raise the question why 14 subjects from the Mississippi attended school but failed to progress. First of all they have been confronted with the new information related to letters and words and naturally with the use of a pencil for drawing. Secondly, they may had have learning disabilities which make them a suspect group on what concerns brain organization.

The second study was carried out in our Laboratory, in Portugal, in 1976 (Damásio *et al.*, 1976a, 1976b) and contradicted Cameron's results. Analyzing a random series of 225 right-handed focal brain-damaged patients,

TABLE 1

Evaluation of 225 right-handed focal brain-damaged patients.

	Number (%) of patients with		
	Left hemisphere lesions		Right hemisphere Lesions
	aphasic	non-aphasic	
Literates (182)	115 (63)	42 (23)	25 (14)
Illiterates (43)	29 (67)	5 (12)	9 (21)

From Damásio *et al.* (1976b).

TABLE 2

Diagnostic criteria for aphasia type.

Type of Aphasia	Speech Fluency	Visual Naming (16 objects)	Oral Comprehension (8 commands)	Word Repetition (30 words)
Broca	non-fluent	< 16	≧ 7	< 23
Global	non-fluent	< 16	< 7	< 23
Wernicke	fluent	< 16	< 7	< 23
Anomic	fluent	< 16	≧ 7	≧ 23
Conduction	fluent	< 16	≧ 7	< 23
Transcortical				
motor	non-fluent	< 16	≧ 7	≧ 23
sensory	fluent	< 16	< 7	≧ 23
mixed	non-fluent	< 16	< 7	≧ 23

From Ferro *et al.* (1980).

we were unable to find any difference between literate and illiterate subjects on what concerns the presence of aphasia following a local brain lesion (Table 1). On the other hand, the severity of aphasia was also reported as being comparable in both groups. It must be stressed at this point that our population of illiterate subjects had never attended school which is crucial for the purpose of this discussion.

Before going forward on the analysis of this problem, we may still add some new information concerning a qualitative analysis of aphasia. Based on our diagnostic criteria of aphasia which stem on the results obtained in laboratorial tests, as shown in Table 2 (Ferro *et al.*, 1980), we correlated

TABLE 3

Distribution of 1358 left hemispheric stroke aphasics per aphasia type (%).

Group	Global	Broca	Wernicke	Conduction	Anomic	Transcortical	Others
(1)	25.4	14.2	15.7	2.6	8.6	9.7	23.9
(2)	24.7	11.6	10.9	3.5	9.9	11.9	27.5
(3)	15.3	16.7	13.4	2.8	9.7	11.1	31.0
(4)	22.2	10.3	12.1	5.5	8.5	9.7	31.5

Groups: (1) – illiterates; (2) 1–4 years; (3) 5–10 years; (4) > 10 years. ns

the type of aphasia with different levels of educational background in 1358 consecutive subjects with left hemisphere strokes that were studied in our Laboratory.

As can be seen in Table 3, no differences were found concerning the distribution per aphasia type. Thus, not only language is most of the time on the left hemisphere, but also a large number of stroke lesions within the left hemisphere produce similar clinical syndromes in all educational levels.

In a series of consecutive papers, Lecours *et al.* reported the results of an international project involving Portuguese and Brazilian patients in several centers (Lecours *et al.*, 1987a, 1987b, 1988).

The first study concerns the analysis of control subjects: literates and illiterates without brain lesions. It was shown that illiterates without brain lesions performed worst on the tests than literate subjects. It was concluded that "when testing brain-damaged patients of different cultural backgrounds one runs the risk of over or underestimating the frequency of aphasia if one does not refer to norms which explicitly take educational level into account". We fully agree with this remark. For the past 20 years we have been dealing with this problem and we have normative data to correct our test scores. Some tests were, however, excluded from our test batteries due to their limited discriminatory power among the illiterate population, like word association and visual naming of drawings.

The results of the test of Visual Naming of drawings of the Multilingual Aphasia Battery in which the subjects are asked to name 41 graphic representations of objects deserve to be reported briefly. The maximum score of this test is 84, the mean score of a group of 19 literate non-brain-damaged subjects was 81.6+/-2.1 against a mean score of 51.6+/-19.4 obtained by a group of 28 non-brain-damaged illiterates ($p < 0.00008$). Several authors have reported severe difficulties in recognizing drawn figures by people

TABLE 4

Distribution of the individual scores of 28 illiterate and 19 literate subjects in a test of Visual Naming of drawings.

Score range	0–30	31–50	51–70	71–80	81–84
Literate (n)	0	0	0	6	13
Illiterate (n)	5	6	13	3	1

untrained to this task (Dawson, 1967; Deregowski, 1980). As a matter of fact, those who are not familiar with written material and have never used a pencil for drawing have great difficulty in transforming a three-dimensional object into a two-dimensional representation. The major problem was, however, the great variability (see Table 4) of the individual scores, which was an impediment to normalize the test for this population. This variability was interpreted on the basis of the individual experience of the subjects and, perhaps, on their own skills for visual analysis. For this reason we use, in our test battery for aphasia, a set of real common use objects which are well named by illiterate controls.

Even tests that are claimed to be less sensitive to cultural variables are poorly performed by illiterates in Portugal. Carlos Garcia and Manuela Guerreiro (1983) in our Laboratory showed that illiterates scored below controls in subtests of the Weschler Memory Scale, in the test of information of the WAIS, in Raven's colored Progressive Matrices and in block design (Table 5). This carries the risk of considering mentally retarded or demented, subjects who are perfectly healthy and successful in their social background.

In the second report, Lecours and collaborators, discuss the interaction of verbal and non-verbal dysfunction based on the results of their test of oral comprehension. Illiterates scored worst than literates in this test as expected because the patients were asked to match a sentence with iconographic materials. Literacy was however irrelevant for the findings that the authors discuss and that concern the interference of neglect in their multiple choice tests.

In 1981 Ferro *et al.* reported the unexpected disturbance in three-dimensional constructional apraxia in illiterate aphasics as compared with literate ones. This was based on the analysis of the results obtained by brain-lesioned patients in the test of three-dimensional apraxia of Benton (Benton and Fogel, 1962). The incidence of constructional apraxia was similar in literates and in illiterates in the groups of right hemispheric lesions (stroke and tumors) and in patients with left hemisphere lesions

TABLE 5

Scores of illiterate and literate control subjects.

Test	Illiterate (mean)	Literate (mean)	
Digit span	6.5	7.8	$p < 0.001$
Block design	9.2	18.1	$p < 0.001$
Information (WAIS)	9.6	15.8	$p < 0.001$
Visual memory	2.5	4.5	$p < 0.01$
Logical memory	6.5	8.4	$p < 0.05$
Raven	5.3	7.8	$p < 0.01$

without aphasia (stroke and tumors). However, constructional apraxia was much more frequent in illiterates in the groups of left hemisphere lesions with aphasia (again both in stroke and in tumor cases). Our interpretation of these findings was that strategy for the execution of the models was language mediated. As we mentioned above, illiterates tend to be more talkative during the execution of the models. Aphasia was, thus, probably responsible for their lower performance. Another possible explanation was based on Gazzaniga's theory that the acquisition of reading and writing, concerning the left temporo-parietal areas, would force the right-sided ones to take care of constructional abilities. Against this interpretation is the finding of similar results in literates and illiterates with right hemisphere lesions. If this were true one would expect to have less constructional apraxia in right hemisphere lesioned illiterates. We have to admit that in illiterates both hemispheres contribute, probably using different strategies, to solve the problems raised by three-dimensional construction.

The third paper of Lecour's group reports the results of 188 unilateral stroke patients when administered an aphasia screening test comprising a short interview as well as naming, repetition, word-picture matching and sentence-picture matching tasks. Their results, with regard to overall error scores on naming tests, showed significant differences within the illiterate population: between control and left stroke subjects and between control and right stroke subjects. Within the literature population there were differences between controls and left stroke subjects but not between controls and right stroke subjects. On the other hand, both controls and patients of the illiterate population, performed worst in all tasks (naming, repetition and matching). However, influence of literacy was only found in the right-stroke group and likewise some degree of word-finding difficulty and of reduction in speech output as well as a sizable production of phonemic paraphasias were observed in the interviews in several right-stroke illiterates. Based on these results the authors suggest that the "cerebral representation of language is more ambilateral in illiterates than it is in school educated subjects although left cerebral 'dominance' remains the rule in both".

We think that another interpretation is possible: naming of iconographic materials by illiterates requires a greater effort, as we discussed above, and, most probably the weight of non-verbal processing of the stimuli which depends on right hemisphere mechanisms is bigger. Word finding difficulties and verbal and phonemic deviations although reported in some right-stroke illiterates did not reach, in their study, a statistically significant difference. These comments may also be made: (1) Word finding within a specific semantic field was shown to be disturbed in right hemisphere lesioned literate subjects compared with normal controls (Joanette *et al.*, 1988). It is acceptable that this effect may be stronger in illiterates due to their inability to recall the words through mechanisms mediated by grammatical rules (which they never learned in life); (2) Phonemic deviations have to be understood on the basis of what has been found concerning phonological awareness of illiterate non-brain-lesioned subjects (see Morais, 1994) and on the fact that phonemic paraphasias are common among normal poor acculturated individuals – this could be a non-specific brain lesion effect.

Two recent reports from South America were addressed to this topic (Ardila *et al.*, 1989; Rosselli *et al.*, 1990). The authors report the results of a large test battery administered to extreme educational groups (non-brain-lesioned illiterates and professionals). The test battery included visuospatial, memory, language and praxic abilities. Although there were differences in most of the subtests related to educational level, we will focus mainly on their results on the language tests:

1. Language comprehension tasks showed differences according to the educational level – most differences were found in complex and semi-complex commands;
2. Phonological discrimination tasks showed differences according to educational level and age – the interaction between them was also significant;
3. Naming real objects was only slightly different between educational groups – only some low education subjects presented scarce mistakes (naming 'bracelet', which none of them used);
4. Naming figures was highly significant for educational level – the older low education group presented the highest number of errors;
5. Naming body parts presented a robust educational effect particularly in finger naming;

6. In word repetition the number of errors was significantly increased in the low educational group;
7. Verbal fluency, which was tested according to phonological or semantic cues, showed significant differences in both subtests for educational level – the differences was much higher on the phonological subtests.

Until now we were able to demonstrate that language lateralization to the left hemisphere is similar in illiterates as in literate based on the evidence of aphasia producing lesions, although there seems to be somewhat different strategies in problem solving that are evidenced in some tasks for which illiterates need the involvement of mechanisms not exactly related to linguistic processing.

The question of the importance of these different strategies on the recovery from aphasia needs also some clarification. As a matter of fact, if the right hemisphere is called to participate in language acts of illiterates one could assume that recovering from aphasia due to a left hemisphere lesion would be easier in illiterates, supporting the anecdotal evidence of the literature. The study of recovery profiles of aphasia is a difficult one. There is an enormous amount of variables that are difficult to control in small series and also a great variability of profiles for which we do not find simple explanations (Castro-Caldas, 1979). In our Laboratory we are conducting a study on the evolution of stroke aphasia in order to evaluate different strategies for speech therapy. From the data we have collected until now it is possible to grasp some information concerning this topic. Using an Aphasia Quotient based on the characteristics of spontaneous speech, naming, oral comprehension and repetition, which correlates well with other measures for aphasia severity (Ferro and Kertesz, 1987) we compared the evolution of literate and illiterate aphasics. Seven consecutive illiterate global aphasics were matched with 14 also consecutive (within the same period of time) literate patients. The variables that were considered for matching the patients were: type and severity of aphasia, age and sex. All patients had suffered ischemic strokes on the left hemisphere, were right handed, were assessed in the same periods of evolution of their disease and were submitted to the same technique of speech rehabilitation. As can be seen in Table 6, there were no differences of the mean Aphasia Quotient at six months of follow-up (scores were naturally similar in the first month).

It can be concluded until now that the incidence, severity, recovery and distribution per aphasia type seems to be similar in literate and in illiterate aphasics. It is still important to know if there are differences in performance in some of the subtests for aphasia evaluation. To study this last problem we selected sequentially from our files 11 global illiterate aphasics and compared the results in some of the subtests with 10 literate global aphasics. These patients were also sequentially selected from the

TABLE 6

Comparison of the evolution of literate and illiterate global aphasics (mean Aphasia Quotient).

	1 month	6 months
Literate (n = 14)	17.3+/-6.3	64.7+/-26.2
Illiterate (n = 7)	19.9+/-12.7	69.7+/-30.9
	n.s.	n.s.

TABLE 7

Comparison of the scores of some subtests for aphasia in literate and illiterate Global and Wernicke's aphasia.

	Object Naming	Comprehension Words	Comprehension Phrases	Token Test	Word Repetition
Global					
Literates (n = 10)	0.0	46.6	36.9	0.7	1.5
Illiterates (n = 11)	4.5	43.2	34.1	0.6	6.9
	n.s.	n.s.	n.s.	n.s.	n.s.
Wernicke's					
Literates (n = 10)	9.7	78.8	48.8	2.0	36.6
Illiterates (n = 10)	4.1	58.7	27.3	0.6	8.5
	n.s.	n.s.	$p = 0.026$	n.s.	$p = 0.003$

files and matched for age and sex. All the patients were studied in the first month following stroke. As can be seen in Table 7 there are no differences in performance in visual naming, object identification, phrase comprehension, Token Test and word repetition. Scores are very low so that differences were difficult to find in these groups of severe aphasia.

Using a similar methodology we compared two groups of Wernicke's aphasics, and the results showed that illiterates performed worst on phrase comprehension and word repetition (Table 7). These results may reflect a bigger deficit in verbal decoding. We can understand the poorer performance on phrase comprehension based on similar arguments to those we used to explain the differences in constructional apraxia. As a matter of fact the test used to assess this function implies the manipulation of objects following oral commands. There are thus similar operative mechanisms that may be mediated through further use of language. The poorer capacity to repeat words may be interpreted as follows: people used to written language, have a more sophisticated phonological auditory decoding which facilitates the access to a larger spectrum of information which may be a preventive for the error production. This control system must be less sophisticated in illiterates.

Based on this idea we tried to study the possible counterpart of this mechanism on the output systems of language, that is, the better control of error production of literate subjects could change the quality of error producing in a test of visual naming. We were unable, however, until now, to find hints of this qualitative differences in these tasks. Aphasic errors are too severe to allow the identification of subtle differences.

GENERAL FINDINGS

The general conclusions are the following:

1. One must be careful in the selection of subjects for studies in illiteracy (there are true illiterates that had never been exposed to written materials and other subjects that do not read and write for different reasons).
2. One must be careful in selecting tests for illiterates (there is a great variability of performances in this population).
3. The studies with brain-lesioned patients suggest that the general correlation between dysfunction and lesion localization is similar both in literates and in illiterates.
4. There are findings that suggest the use of different strategies to solve problems in the illiterate population, which reflect on their abnormal performances after brain lesions.

REFERENCES

Ardila, A., Rosselli, M. and Rosas, P.: 1989, 'Neuropsychological assessment in illiterates: Visuospatial and memory abilities', *Brain and Cognition* **11**, 147–166.

Benton, A. L. and Fogel, M. L.: 1962, 'Three-dimensional constructional praxis – A clinical test', *Archives of Neurology* **7**, 347–354.

Cameron, R. F., Currier, R. D. and Haerer, A. F.: 1971, 'Aphasia and literacy', *British Journal of Disorders of Communication* **6**, 161–163.

Castro-Caldas, A.: 1979, *Diagnóstico e evolução das afasias de causa vascular*, Doctoral Thesis, Lisbon.

Castro-Caldas, A.: 1991, 'Crossed aphasia as a model of atypical specialization', in P. Martins *et al.* (eds.), *Acquired Aphasia in Children: Acquisition and Breakdown of Language in the Developing Brain*, Kluwer Academic Publishers, Dordrecht, pp. 83–93.

Curtiss, S.: 1977, *Genie: A Psycholinguistic Study of a Modern-Day 'Wild-Child'*, Academic Press, New York.

Damásio, A. R., Castro-Caldas, A., Grosso, J. T. and Ferro, J. M.: 1976a, 'Brain specialization for language does not depend on literacy', *Archives of Neurology* **33**, 300–301.

Damásio, A. R., de S. Hamsher, K., Castro-Caldas, A., Ferro, J. M. and Grosso, J. T.: 1976b, 'Letter to the Editor', *Archives of Neurology* **33**, 662.

Dawson, J. L. M.: 1967, 'Cultural and physiological influences upon spatial perceptual processes in west Africa, part 1', *International Journal of Psychology* **2**, 115–128.

Deregowski, J. B.: 1980, *Illusions, Patterns and Pictures: A Cross-Cultural Perspective*, Academic Press, London.

Ferro, J. M., Santos, M. E., Castro-Caldas, A. and Mariano, M. G.: 1980, 'Gesture recognition in aphasia', *Journal of Clinical Neuropsychology* **2**, 277–292.

Ferro, J. M., Castro-Caldas, A., Martins, I. P. and Salgado, V.: 1981, 'Verbal and visuospatial disturbances: Influence of literacy', paper presented at the *4th INS European Conference*, Bergen.

Ferro, J. M. and Kertesz, A.: 1987, 'Comparative classification of aphasic disorders', *Journal of Clinical and Experimental Neuropsychology* **9**, 365–375.

Garcia, C. and Guerreiro, M.: 1983, 'Pseudo dementia from illiteracy', paper presented at the *6th INS European Conference*, Lisbon.

Geschwind, N. and Levitsky, W.: 1968, 'Human brain left right asymmetries in temporal speech region', *Science* **161**, 186–187.

Joanette, Y., Goulet, P. and Le Dorze, G.: 1988, 'Impaired word naming in right-brain-damaged right-handers: Error type and time-course analysis', *Brain and Language* **34**, 54–64.

Lecours, A. R., Mehler, J., Parente, M. A. *et al.*: 1987a, 'Illiteracy and brain damage: 1. Aphasia testing in culturally contrasted populations (control subjects), *Neuropsychologia* **25**, 231–245.

Lecours, A. R., Mehler, J., Parente, M. A. *et al.*: 1987b, 'Illiteracy and brain damage: 2. Manifestations of unilateral neglect in testing 'auditory comprehension' with iconographic materials', *Brain and Cognition* **6**, 243–265.

Lecours, A. R., Mehler, J., Parente, M. A. *et al.*: 1988, 'Illiteracy and brain damage: 3. A contribution to the study of speech and language disorders in illiterates with unilateral brain damage (initial testing)', *Neuropsychologia* **26**, 575–589.

Morais, J.: 1993, 'Phonemic awareness, language and literacy', in R. M. Joshi and C. K. Leong (eds.), Kluwer Academic Publishers, Dordrecht, pp. 175–184.

Ostrosky, F., Canseco, E., Quintanar, L., Navarro, E., Meneses, S. and Ardila, A.: 1985, 'Sociocultural effects in neuropsychological assessment', *International Journal of Neuroscience* **27**, 53–66.

Ostrosky, F., Quintanar, L., Meneses, S., Canseco, E., Navarro, E. and Ardila, A.: 1986, 'Actividad cognoscitiva y nivel sociocultural', *La Revista de Investigacion Clinica* **38**, 37–42.

Rosselli, M., Ardila, A. and Rosas, P.: 1990, 'Neuropsychological assessment in illiterates: II. Language and praxic abilities', *Brain and Cognition* **12**, 281–296.

Teszner, D., Tzavaras, A., Gruner, J. and Hécaen, H.: 1972, 'L'assymétrie droît-gauche du planum temporale: A propos de l'étude anatomique de 100 cerveaux', *Revue Neurologique* **179**, 444–448.

PART 2

CASE STUDIES

EDITORS' COMMENTS

Just as neurological data including in vivo visualization of brain morphology and neuropsychological studies enhance the reliability and validity of the diagnosis and treatment of developmental dyslexia; so too, detailed neurolinguistic analysis of the clusters of features of acquired dyslexia and aphasia in affected individuals add to our understanding of these acquired language disorders. Aphasia is explained by Damasio (1992, p. 531) in a review from the vantage point of neurology and neuroscience as: "a disturbance of the comprehension and formulation of language caused by dysfunction in specific brain regions. It results from a breakdown of the two-way translation that establishes a correspondence between thoughts and language."

Current notions of the mapping between cognitive and linguistic activities and functional cerebral regions go beyond the classical view of the aphasias associated with damage to specific brain areas. Our better understanding of mental representations of aphasics and acquired dyslexics derives more from detailed case reports than from taxonomic classification of patients (see Coltheart *et al.*, 1980; Patterson *et al.*, 1985). While group studies show patterns of impairment, they many not permit fine-grained inferences of the architecture of the cognitive and linguistic components and their neural correlates (Caramazza, 1988).

From the aphasiological and neuropsychological literature, the 'symptom-complex' of aphasia is characterized by multidimensional mechanisms with groups of features indicating specific disorders in certain cerebral regions subserved by vast neuronal networks (Damasio, 1992; Marshall, 1982). Support for the multidimensional notion of acquired language disorders comes from several sources. One source of evidence derives from patients with selective damage to different components of the lexical system. For example, Goodman and Caramazza (1986) found in their patient damage to the output graphemic lexicon but relatively normal performance in other components of the lexical systems. The other source of evidence suggests that different kinds of dysfunction are associated with different components of the lexicon. In a detailed analysis of their patient KE's semantic paralexic reading errors (e.g., 'apple' read as 'orange', Hills *et al.* (1990) tested different hypotheses of the locus of the occurrence of these semantic reading errors. They suggested that these errors result from selective damage to the modality-independent semantic

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system involved in lexical processing. The assumption is that the lexical entry is activated in the input graphemic lexicon, but fails to activate the output phonological lexical system; and instead activates a semantically related entry. The claim is that distinct neural processes are activated with different cognitive-linguistic mechanisms and that brain pathology may selectively impair different components of a distributed lexical system.

The different case studies and the neurolinguistic data in this Part 2 should be read within the above context. The team of **van Vugt, Paquier, Bal, Creten, and Martin** reports on the 'stabilized aphasiological picture' of a Dutch speaking deep dyslexic patient LG in his lexical production during regular follow-ups in 1988 and 1989. It will be recalled that Marshall and Newcombe (1980, p. 1) 'insinuated' in deep dyslexics the existence of a symptom-complex characterized by predominant semantic errors, within the context of derivational and visual errors, in reading aloud single words (untimed and decontextualized). In three detailed studies with careful analyses, van Vugt *et al.* found a consistency effect in LG's single word reading. The patient's semantic errors showed less perseveration and marked increase in 'conduites d'approche sémantiques' or repetitive production of semantically related lexical items before successful or unsuccessful rendering of the target word. In the analyses of free word association responses of LG, van Vugt *et al.* found fewer tangentially linked associations, possibly because of less spreading activation. Their overall interpretation of the follow-up studies is in terms of 'defective lexical search in a networklike lexicon' and a 'grammar-mediated compensatory strategy'.

One of the related findings of van Vugt *et al.* was a shift from imageability to frequency effects in LG's word reading and this shift was explained by the authors as related to intra-patient variability. The issue of the visual or imageability component was studied by **Kremin** in a deep dysgraphic patient GI. The central question was the extent to which GI relied on the visual component while using imageability as a compensatory strategy. The error patterns in the patient's writing from dictation for various stimulus materials such as letters, digits, acronyms, common and proper names suggest that imageability may have little explanatory power for dysgraphia; and proper nouns may arouse some schemata or 'stories' rather than images. These results lead to the further suggestion by Kremin that deep dysgraphic writing and deep dyslexic reading may be multicomponential or multidimensional. While there may be modality-specific and functionally independent input and output lexicons, available evidence is strongly suggestive of an interconnected, modality-independent distributed lexical system (Caramazza and Hillis, 1991; Damasio, 1992).

In his detailed report, **Kihl** investigated lexical agraphia in a twenty-one-year old right-handed Danish patient SL with multifocal brain injuries with right-sided predominance. While the broad framework was a modified dual route model to incorporate sublexical assembly processes in spelling in the relatively 'irregular' Danish orthography, the case report makes some cautious comparison with parallel distributed processing as a plausible explanation of SL's spelling errors. The analyses of SL's spelling in ten essays with a corpus of 2934 words show 30% spelling errors with 92% of these errors as 'phonemic errors in orthographically irregular words', 5% 'hypercorrections' and some 2% as 'muddled spelling'. The sound-complex errors in this Danish patient included lack of correspondence between letter sounds and letter names, 'silent' letters, omissions of consonant clusters, and errors in glottal stop groups; while hypercorrections referred to plausible letter names not corresponding to the appropriate sounds. From his fine-grained analyses, Kihl suggests that the error magnitude of SL may be of similar order to other such patients, and discusses his patient's 'Wernicke-type' paraphasic errors, or substitutions of plausible but erroneous individual phonemes or entire words for the intended or correct target sounds or words.

Moving from patients to neurologically intact subjects, **Kaufman and Obler** outline their compilation of 573 errors in newspaper and magazine reading from two women in their late thirties and early forties; and suggest substitutions and heterogeneous errors as their main error categories. It should be noted that for both 'normal' and dyslexic reading or spelling errors, classification is not easy because of the interweaving of the phonological, morphological and word-specific strands, and both quantitative and qualitative differences in phonological and orthographic errors will need to be delineated and assessed.

The manifestations of Landau–Kleffner syndrome (LKS) and their effect on progressive aphasia and behavior problems of a ten-year-old LKS boy is the subject of the summary report by **da Silva and Nunes**. In essence, Landau–Kleffner syndrome refers to localized abnormalities definable by EEG (possibly PET) in which the focus is mainly the left hemisphere with epileptic seizures associated with language impairment. One question relates to whether suppressing the abnormal electrographic discharges might lead to improved linguistic and behavioral performance of the individual affected. The authors suggest that physiological disruptions shown by subclinical epileptiform EEG discharges might explain the language impairment of these individuals. There is the further suggestion from neurological perspectives that there might be microscopic cortical abnormalities, similar to those seen in some dyslexics, that are associated with the EEG anomalous discharges (D. D. Duane, personal communication, July 1992).

To bring together the commentaries on these five reports in Part 2, at least two issues will need to be raised. One is methodological pertaining to individual data from single-case studies and with bearing on substantive aspects. The other is the explicitly stated or implied acceptance of cognitive and linguistic activities subserved by complex processes involving different modalities and in hierarchies distributed over the whole brain.

On the issue of single-case studies versus, or complementing, group data, Bates and her colleagues (Bates, Appelbaum and Allard, 1991; Bates, McDonald, MacWhinney and Appelbaum, 1991) discuss in considerable detail the problems of measurement of case studies and group data. For case reports, information must include base rate of performance, reliability of the tasks and the assumption of the underlying distribution (linear or curvilinear) so as to minimize spurious single and double dissociation effects. Bates, McDonald, MacWhinney and Appelbaum (1991, p. 245) emphasize "a [language] model that predicts specific patterns of interaction among a series of within-subject variables" tested across many different individuals, in many different situations, and under different conditions to obtain extended and exhaustive information. They also explicate the maximum likelihood estimation (MLE) technique with detailed statistical indices such as goodness-of-fit and residuals as a powerful means in showing the patterns of main effects and interactions for affected aphasic individuals and in comparison with normal or other patient controls.

Conceptually, the papers by van Vugt *et al.*, Kremin and Kihl all acknowledge in varying degrees the current emphasis on an interconnected distributed approach to the lexical system and computationally explicit structure of language processing. This conceptualization of the neural systems subserving complex cognitive and linguistic functions is aptly stated as the result of 'synchronized activity in vast neuronal networks made up of many functional regions in the cerebral cortex and subcortical nuclei and numerous pathways that interconnect these regions in reciprocal fashion" (Damasio, 1992, p. 532). Accounts of the computationally explicit parallel distributed processing and simulations are given in some of the chapters in Part 3.

REFERENCES

Bates, E., Appelbaum, M. and Allard, L.: 1991, 'Statistical constraints on the use of single case in neuropsychological research', *Brain and Language* **40**, 295–329.

Bates, E., McDonald, J., MacWhinney, B. and Appelbaum, M.: 1991, 'A maximum likelihood procedure for the analysis of group and individual data in aphasia research', *Brain and Language* **40**, 231–265.

Caramazza, A.: 1988, 'Some aspects of language processing revealed through the analysis of acquire aphasia: The lexical system', *Annual Review of Neurosciences* **11**, 395–421.

Caramazza, A. and Hillis, A. E.: 1991, 'Modularity: A perspective from the analysis of acquired dyslexia and dysgraphia', in R. M. Joshi (ed.), *Written Language Disorders*, Kluwer Academic Publishers, Dordrecht, pp. 71–84.

Coltheart, M., Patterson, K. E. and Marshall, J. C. (eds.): 1980, *Deep Dyslexia*, Routledge & Kegan Paul, London.

Damasio, A. R.: 1992, 'Aphasia', *The New England Journal of Medicine* **326**, 531–539.

Goodman, R. A. and Caramazza, A.: 1986, 'Aspects of the spelling process: Evidence from a case of acquired dysgraphia', *Language and Cognitive Processes* **1**, 263–296.

Hillis, A. E., Rapp, B., Romani, C. and Caramazza, A.: 1990, 'Selective impairment of semantics in lexical processing', *Cognitive Neuropsychology* **7**, 191–243.

Marshall, J. C.: 1982, 'What is a symptom-complex?', in M. A. Arbib, D. Caplan and J. C. Marshall (eds.), *Neural Models of Language Processes*, Academic Press, New York, pp. 389–409.

Marshall, J. C. and Newcombe, F.: 1980, 'The conceptual status of deep dyslexia: An historical perspective', in M. Coltheart, K. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 1–21.

Patterson, K. E., Marshall, J. C. and Coltheart, M. (eds.): 1985, *Surface Dyslexia: Neuropsychological and Cognitive Studies of Phonological Reading*, Lawrence Erlbaum, Hillsdale, NJ.

P. VAN VUGT, P. PAQUIER, P. BAL, W. CRETEN, AND J.-J. MARTIN

SEMANTIC ERRORS AND FREE WORD ASSOCIATIONS: SOME REMARKS ON LEXICAL SEARCH ACTIVITY IN STABILIZED APHASIA

ABSTRACT. Different hypotheses have been made in order to explain the occurrence of semantic errors made by deep dyslexic patients. We present a series of three experiments of lexical production in a single case-study: firstly consistency measurements in single word reading, secondly frequency counts of semantic errors occurring during visual picture-naming and single word reading, and thirdly quantitative and qualitative analyses of free word association responses. Although in our Dutch-speaking patient a stabilized aphasia is documented, test results demonstrate an intra-patient profile variability in the deep dyslexic reading performance. Furthermore, we propose to explain the occurrence of semantic errors by a defective lexical search activity in a networklike lexicon and by a grammar-mediated compensatory strategy.

INTRODUCTION

Semantic errors occurring in patients with language disorders due to brain damage have always been of particular interest to cognitive scientists and clinicians. More recently, these errors have been considered the nucleus of a reading or more general language disturbance known as 'deep dyslexia' (Coltheart, 1980a, Coltheart *et al.*, 1987). Various attempts were made to explain these errors, but most frequently, the proposed theories seem to accept that the basic problem is one of not being able to select the correct target word from a wide range of words activated by the stimulus word (see Franz, 1930).

In an attempt to enhance our understanding of the processes generating semantic errors, Coltheart (1980b) distinguishes two types of errors: the associative type and the one in which stimulus and response (S–R) share a great number of Forod and Katz' (1964) features. Another conceptual pair which Coltheart (1980b) assimilated to this distinction is that of syntagmatic errors (e.g. short → walk) and paradigmatic errors (e.g. robin → bird).

A second point of interest concerns the uni- or plurimodality of the deep 'dyslexic' disturbance. The accumulating literature on the subject suggests that qualitatively similar patterns can be found in picture naming, word repetition, writing to dictation, as well as in word-picture matching tasks (Coltheart *et al.*, 1987). However, Marshall *et al.* (1970) documented

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a clear difference between word production and comprehension in their patient. This did not prevent investigators exploring the underlying causes of the semantic errors, from matching reading test material with tasks requiring word recognition or comprehension (Friedman and Perlman, 1982; Kapur, 1980).

In the present study, which was undertaken in order enhance insight into the processes leading to semantic errors, we used three exclusively expressive language tests: a single-word reading test, a single-object picture naming test, and an orally presented free word association (FWA) test.

CASE HISTORY

L.G. is a left-handed, Dutch-speaking woman known since 1980 with a neurofibromatosis of von Recklinghausen and a gliotic tumor of the optic chiasma. When the first reading profile analysis reported here took place (1988) she was a 25-year-old. No disorders of the higher mental functions were observed until February 1986 when she became hemiplegic and aphasic following a left fronto-temporal cerebro-vascular accident. The neurolinguistic assessment in the peri-acute stage and the follow-up examination three months post-onset showed an evolution from mixed transcortical aphasia (MTA) to transcortical motor aphasia (TMA), with a marked improvement of auditory comprehension and a near-normal repetition of phonemes, words and short sentences. The non-fluent verbal output, in which also semantic paraphasias occurred, was agrammatic and perseverative. Semantic paralexias occurred during single-word reading. Sentence reading was hardly possible. Reading comprehension was better for isolated words than for sentences during a picture pointing task. A severe agraphia was observed.

Regular follow-ups did not show significant changes in word and sentence comprehension (Dutch translations from the *Boston Diagnostic Aphasia Examination* (Goodglass and Kaplan, 1972) and the *Aachener Aphasie Test* (AAT) (Huber *et al.*, 1983).) No changes in phoneme, word and sentence repetition performances since 1986. Further, still non-fluent and agrammatic spontaneous speech, near normal copying of graphemes, words and sentences, and little score progress on the clinical writing to dictation test used in our unit.

The patient presented a deep dyslexic reading behaviour (see Paquier *et al.*, 1992). Clinical neurological examination at the time of the first detailed reading assessment (May 1988) revealed a right residual sensorimotor deficit and a blindness of the right eye, a normal visual acuity of the left eye with a visual field defect in the left upper temporal quadrant.

So-called visual paralexias were independent of the visual field deficit. In 1989, the patient had an IQ of 90 on the SPM (Raven, 1958).

METHOD

Experiment 1: Consistency Measurement of the Oral Reading of Isolated Words

The FLIRT-120 single-word reading test developed by one of us (van Vugt) in order to measure the effect of word class, word length, word frequency, and imageability (see Paquier *et al.*, 1992) on the reading performance of Dutch-speaking patients, was administered twice to L.G. (May 1988 and July 1989).

Firstly, we wanted to compare the number of L.G.'s successful responses of both test sessions. Secondly, we wanted to establish the degree of consistency of the reading errors. We maintained Barry's (1984) categorisation into *correct responses*, *omissions* (when a real word had to be read), *semantic*, *visual*, *visual and/or semantic* and *derivational* errors. Moreover, we distinguished between the *correct reading of a non-word* reported in deep dyslexic readers by Coltheart (1980a) and Shallice and Warrington (1980) and *non-word reading resulting in a neologism* (see G.R.N.'s response *nup–yem* in Shallice and Warrington (1980)) or in its *omission*. In order to account for the particular type of response consisting in producing a real word (or name) when a legal non-word is presented, we distinguished two other categories: *lexicalisations which can possibly be visual errors* (Marshall and Newcombe, 1980; Shallice and Warrington, 1980) and *straight lexicalisations* (Marcel, 1980; Marshall and Newcombe, 1980). A particular behaviour of deep dyslexic patients having been familiarized with the de Partz (1986) strategy during rehabilitation session, may consist in describing as accurately as possible the target word by spelling it or, as the strategy is only partially applied, by naming objects or enumerating proper names beginning with the same letter as the one that is being read. We called these approaches of the target, *word descriptions*. We did not distinguish single and multiple word responses since they are not always considered different classes (see Coltheart *et al.*, 1980, pp. 412–422). In our opinion, multiple element responses can easily be classified on a 'most striking feature' basis. Possible ambiguous responses are listed together with the *unclassifiable answers*.

TABLE 1

Frequency of the error types made by L.G. during visual picture naming.

	Month–Year							
	3–86		6–86		5–88		7–89	
Response types	*n*	%	*n*	%	*n*	%	*n*	%
word completion								
– correct	8	8.6	12	18.2	6	8.6	0	0.0
– word perseveration	7	7.5	0	0.0	1	1.4	0	0.0
– morpheme error	1	1.1	0	0.0	0	0.0	0	0.0
– verbal paraphasia	4	4.3	3	4.6	5	7.1	1	2.0
– phoneme error	3	3.2	0	0.0	0	0.0	0	0.0
– neologism	1	1.1	0	0.0	0	0.0	0	0.0
– semantic error	0	0.0	1	1.5	0	0.0	0	0.0
– no response	0	0.0	0	0.0	1	1.4	0	0.0
picture naming								
– correct	0	0.0	8	12.1	12	17.1	16	31.4
– word perseveration	27	29.0	0	0.0	3	4.3	1	2.0
– embolalia	21	22.6	16	24.2	15	21.4	4	7.8
– conduite d'approche	15	16.1	3	4.6	2	2.9	1	2.0
– semantic paraphasia	0	0.0	1	1.5	2	2.9	3	5.9
– semantic intrusion	0	0.0	0	0.0	2	2.9	1	2.0
– morpheme error	0	0.0	2	3.0	1	1.4	2	3.9
– verbal paraphasia	1	1.1	3	4.6	1	1.4	1	2.0
– phoneme error	0	0.0	0	0.0	2	2.9	1	2.0
– function word addition	5	5.4	12	18.2	13	18.6	15	29.4
– description	0	0.0	1	1.5	4	5.7	3	5.9
– apology	0	0.0	4	6.1	0	0.0	2	3.9
Total number of lexies	93		66		70		51	
Difference of the profiles		s		ns		ns		

s: $p < 0.001$ ns: $p > 0.05$; n: number of responses

Experiment 2: Comparison of the Frequency of Semantic Errors Occurring during Visual Object Naming and Single Word Reading

The visual confrontation naming test of the *AAT* (Huber *et al.*, 1983), is an appropriate parallel of our experimental word reading test, because it only requires production of single words. It was administered four times

TABLE 2

Criteria of the 100 free word association stimulus items.

5 ∗ 20 item groups and examples	mpaf	criterion
– high frequency primary response *answer* ⟶ *question*	71.50	mpaf > 60
– asymmetrically double linked *sun* ⟶ *moon*	57.45	mpaf difference > 12
– symmetrically double linked *army* ⟶ *soldier*	37.35	mpaf difference < 12
– idiomatic sequence *lump* ⟶ *throat*	30.70	
– low frequency primary response *land* ⟶ *52 different responses*	14.00	29 or more different responses

mpaf: mean primary association frequency of normal individuals

during the follow-up period (see Table 1). Because of the lasting naming difficulties, and in order to maintain a certain psychological comfort, phoneme prompts were given during test administration. For this reason we distinguished two major response types: firstly, lexical productions where the response latency was less than or equal to 5 seconds; secondly, the answers following picture confrontation resulting in a naming difficulty (and response latency greater than 5 seconds) for which prompting was used, thus requiring word completion. In analyzing the tape recorded performances, we used the response classification mentioned in Table 1. The unit for the frequency count is the 'lexy' as defined by Schifko (1977, p. 63), which includes words, morphemes, and idiomatic sentences.[1] The descriptive behaviour already mentioned may result in an enumeration of proper names or names of objects. Since the target of the patient's effort is not the series of words, but only their first letter, we considered these word descriptions to be one unit. Because one picture may elicit a different number of lexies at different moments, we calculated the percentage of occurrence of each category on the total number of lexies uttered at a particular testing date.

Experiment 3: L.G.'s Performance on a Free Word Association Test

a. The stimuli

The 100 stimuli were selected from De Groot's (1980) 460 item list. A tendency to give more atypical or unconventional responses has been reported in elderly (over 65 years of age) and in dementing patients (Gewirth *et al.*, 1984; Randolph, 1991; Santo Pietro and Goldfarb, 1985), as well as in some aphasics (Gewirth *et al.*, 1984; Wyke, 1962). In an attempt to prevent idiosyncratization of the responses we selected 80 stimulus items which have a strong link with their primary response (i.e., the most frequently given response to a stimulus by normal controls). A set of 20 items was chosen to contrast with these strongly linked responses. The criterion for the 'liberty' of these links was the number of different associated words. The strength of the more powerful links was determined by various types of S–R relations (see Table 2).

b. Procedure

The patient was tested in a quiet room. The instructions for the FWA test were similar to those given in previous studies (De Groot, 1980; Santo Pietro and Goldfarb, 1985). Four examples were given by one of the two examiners: *love–hate* (antonym), *fly–mosquito* (coordinate), *trunk–branch* (tangential link) and *salt–gold* (phonological resemblance in Dutch). It was made clear the associations did not have to be of one particular type. When it was obvious the patient had understood the task, the stimuli list was read word by word. The responses were tape recorded and written verbatim. There was no time pressure, but we only took into account the first lexy given.

c. Classification of the responses

In an interdisciplinary review the results of several and often very different research projects on human categorization processes Lakoff (1987) emphasized the artificial character of the act of categorizing. Nevertheless, we tried to classify L.G.'s FWAs according to the procedure proposed by Santo Pietro and Goldfarb (1985). Three certified neurolinguists independently evaluated 3054 different S–R pairs produced by the normal control subjects (De Groot, 1980) and L.G.'s 100 pairs.. In two meetings each pair was discussed if necessary and definitively classified, whereby majority prevailed on consensus.

We used a wide range of association type classes. Some of the categories used (Table 3) are well known and in current use in the literature on FWAs (Buckingham and Rekart, 1979; Coltheart, 1980b; De Groot, 1980; Galton, 1879; Jung and Rilkin, 1904/1973; Salus, 1980; Santo Pietro and

TABLE 3

Frequency of the free word association stimulus-response types in normal individuals and in L.G.'s performance.

Category Dutch example	English equivalent	L.G.	NL.	S	STD
A. Paradigmatically linked responses					
– *tangential**		14	2794	x	
mes → slager	(knife–butcher)				
– *superordinate**		6	1173		
leeuw → dier	(lion–animal)				
– *coordinate**		10	977		
leeuw → tijger	(lion–tiger)				
– *subordinate**		8	556		
baard → sik	(beard–goatee)				
– *cause and effect**		4	248		
ei → kip	(egg–chicken)				
– *synonym**		4	303		
kat → poes	(cat–puss)				
– *antonym**		12	752		
heer → dame	(lord–lady)				
– *egocentric*		0	34		
dochter → heb ik niet	(daughter–I have not)				
– *nonsense or idiosyncratic*		3	50		x
– *misunderstood stimulus*		2	14		x
kaf–(kaft) → boek	(chaff–(cover)–book)				
B. Syntagmatic classification criteria					
– *phoneme addition to create a new word*					
– prepositive		0	3		
tak → mare	(branch–mistletoe)				
– postposition		2	23		
lam → lamp	(lamb–lamp)				
– *phonological similarity*		0	35		
hol → bol	(cave–sphere)				
– *bound morpheme completion*					
– prepositive		0	0		
loop → verloop	(course)				
– postposition		11	24		x
leeuw → leeuwin	(lion–lioness)				

TABLE 3

(Continued)

Category Dutch example	English equivalent	L.G.	NL.	S	STD
B. Syntagmatic classification criteria (continued)					
– *free morpheme completion*					
– prepositive*		1	118		
dag → maandag	(day–monday)				
– postposition*		1	358		
ei → eierdop	(egg–egg-cup)				
– substitution*		0	10		
hooiberg → hooikoorts	(haystack–hay fever)				
– postposition with deletion of an element*		0	56		
leeuw-(e) → bek	(lion–antirrhinum)				
– *idiomatic completion*					
– prepositive		3	316		
leeuw → hol	(put one's head in the lion's mouth)				
– postposition		5	816		
mand → vallen	(to fail as . . .)				
– *functionally related verb*		5	504		
bad → vollopen	(bath–to fill)				
– *attribute*		1	658	x	
muis → klein	(mouse–small)				
– *syntagma completion*					
– prepositive		0	16		
aarde → moeder	(earth–mother)				
– postposition		7	62		x
beenhouwer → verkoopt	(butcher–sells)				
– *onomatopoeia*		0	10		
mug → zzzzz	(mosquito)				
– *perseveration*		0	0		
kaas → kaas	(cheese)				
– *O-response*		1	58		
Total number of responses		100	9968		

The responses involving predominantly lexical irradiation activity are marked *.
S: $p < 0.05$; STD: the number of L.G.'s responses > 2 standard deviations.

TABLE 4

Quantitative reading profile per imageability, frequency and length.

Item Characteristics		High 40 items		Low 40 items		X^2 significance	
	Year	1988	1989	1988	1989	1988	1989
I	raw score	28	31	18	26	s	ns
	% correct	70	77	45	65		
F	raw score	23	34	23	23	ns	s
	% correct	57	85	57	57		
L	raw score	31	35	15	22	ns	ns
	% correct	51	58	37	55		
		60 items short		40 items long			

I: imageability; F: frequency; L: length; s: $p \leq 0.05$; ns: $p > 0.05$.

Goldfarb, 1985; Wyke, 1962). In order to avoid the risk of *ad hoc* classifications, we decided to group together all the S–R pairs in which there is "some degree of [semantic] relation (albeit indirect or remote)" (Wyke, 1962, p. 682), and to call them, as Wyke did, "*tangential relationships*". We also went somewhat further than De Groot (1980) in distinguishing not only *morpheme completions* from the *addition of one or more phonemes to form another word*, but also *bound morpheme completions*, i.e., a phenomenon that, to our knowledge, has not yet been reported in the literature.[2] Another S–R pair distinction we would like to propose concerns pairs like: *butcher–to sell* which we consider as pertaining to the *functionally related verb* category, and those like *butcher–sells* which would be a *syntagmatic completion*.

RESULTS

Experiment 1

The 1989 reading profile shows a significant word frequency effect, which was not present in 1988, and conversely, the significant imageability effect noted in 1988 has disappeared (Table 4). The word class profiles of 1988 and 1989 are not significantly different (G = 2.61 vs. X^2 = 11.07 and p = 0.05) (Table 5). Function words, however, in contrast to the 1988 profile

TABLE 5

Quantitative part of speech reading profile.

		Year	IN	L	FW	VE	AD	RN
raw score		1988	16	0	11	10	14	11
out of 20		1989	14	1	9	15	17	16
% correct		1988	80	0	55	50	70	55
		1989	70	5	45	75	85	80
X^2	RN	1988		s				
significance		1989		s	s			
	AD	1988		s				
		1989		s	s			
	VE	1988		s				
		1989		s				
	FW	1988		s				
		1989		s				
	L	1988	s					
		1989	s					

s: $p \leq 0.05$
IN: irregularly spelled nouns; FW: function words
VE: verbs; AD: adjectives; RN: regularly spelled nouns; L: logatomes

(content words (48/80) vs. function words (11/20): $G = 0.02$ vs. $X^2 = 3.84$ and $p = 0.05$), in 1989 are read significantly worse than content words (content words (62/80) vs. function words (9/20): $G = 6.70$ vs. $X^2 = 3.84$ and $p = 0.05$). This shift is due to the worse reading of function words and the better reading of regularly spelled nouns, verbs and adjectives. It is also to be noted that one non-word has been read correctly during the 1989 test session.

Table 6 shows that for 72 words L.G.'s reading behaviour remains of the same nature, which means there is a consistency factor of 60%. The shifts in the qualitative profile are not significant ($G = 10.24$ vs. $X^2 = 21.02$ and $p = 0.05$).

Experiment 2

The response patterns recorded during the four administrations of the visual confrontation naming task (Table 1) differ very significantly, as revealed

TABLE 6
Error type consistency table.

		1989												
RT		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
	nR	1	71	3	15	1	4	4	4	2	1	0	10	4
1988														
1. non-word correctly read	0													
2. real word correctly read	62		53		5		1		2				1	
3. lexicalization and/or visual paralexia	2			2										
4. visual error	12		3		6		1		1					1
5. visual and/or semantic error	1					1								
6. derivational error	7		3				2						2	
7. lexicalization	4			1				1			1		1	
8. description	4	1			1			2						
9. omission of a non-word	5							1	1	2			1	
10. non-word read as a neologism	0										1			
11. semantic error	4		3											1
12. unclassifiable response	12		4		3								4	1
13. omission of a real word	7		5										1	1

RT: Response types
nR: number of responses of each type

by a 20 × 4 contingency table ($G = 215.62$ vs. $X^2 = 86.66$ and $p = 0.001$).[3] Detailed analysis shows that the significant shift, responsible for this high G value, occurs between the first and the second administration, since 20 × 2 contingency tables reveal the following values: 3–86/6–86: $G = 66.84$ vs. $X^2 = 43.82$ and $p = 0.001$; 86/87: $G = 20.94$ vs. $X^2 = 30.14$ and $p = 0.05$; 88/89: $G = 19.93$ vs. $X^2 = 30.14$ and $p = 0.05$. Although the increasing number of correct responses is important in distinguishing statistically the four response patterns, the major shift effect nevertheless is due to the disappearance of perseverative responses and the marked decrease of conduites d'approche.

The number of semantic paralexias occurring during single-word reading is not significantly different from the number of semantic paraphasias occurring during visual picture naming ($G = 0.25$ and $G = 3.45$ respectively in 1988 and 1989 vs. $X^2 = 3.84$ and $p = 0.05$).

Experiment 3

Analysis of the FWA test results presented in Table 3 shows that L.G. gives significantly fewer tangentially linked associations ($G = 9.00$ vs. $X^2 = 7.87$ and $p = 0.005$) and responses of the attributive type ($G = 4.20$ vs. $X^2 = 3.84$ and $p = 0.05$) than normals. Moreover, the number of bound morpheme completions, syntagma completions, and nonsense responses, as well as the number of misunderstandings of the stimulus word was 2 standard deviations above the respective normal means. The number of responses involving lexical irradiation activity (∗ marked) is significantly lower in L.G. than in the normal control individuals ($G = 8.84$ vs. $X^2 = 7.88$ and $p = 0.005$).

DISCUSSION

Evidence for a stabilized aphasiological picture in our patient can be found in several of her test performances. Detailed analysis of the response type profiles of the visual naming test shows that the only significant shift in the picture naming performance occurred within the first three months post onset. This parallels the observation of the clinical picture of evolution from MTA to TMA. Besides the marked reduction of the conduites d'approche, the most striking feature of this profile shift is the almost total disappearance of perseverative responses. This finding confirms the earlier observations reviewed by Albert and Sandson (1986), that the number of perseverations decreases in relation to the time elapsed since onset, however with the significant changes being observed during the first year. A second argument in favour of L.G.'s stabilized aphasia is obtained from her single-word reading error type consistency factor (60%).

Although our findings show the stability of L.G.'s language disorder, a few unexpected but significant shifts occur in the quantitative reading profile analysis. The absence of semantic errors during the 1989 FLIRT-120 reading session is merely a matter of bad luck for the examiners. At the same date several semantic errors in spontaneous speech, sentence reading and visual naming (see Table 1), were observed. The low frequency of the semantic errors could not be held against a positive diagnosis, since patients having produced only one semantic error have been considered as deep dyslexic (Kremin, 1984). What is important for the deep dyslexia diagnosis is the constellation of the different traditionally described reading deficits and performance characteristics. In this line of arguing, one has to admit that L.G.'s deep dyslexic reading pattern became even more convincing, since in 1989 there was a significant better reading of content than of function words, a feature absent in 1988.

However, the reasons for the somewhat surprising shift from a significant imageability effect to a significant frequency effect in single word reading remain unclear. The imageability effect is listed in the original 12-element symptom-complex (Coltheart, 1980a), in Shallice and Warrington's (1980) overview of the '4 key features', as well as in the in the remaining 8-symptom-complex (Coltheart *et al.*, 1987). However, Coltheart (1980a) mentions a concreteness/abstractness effect in only 11 of the 22 at that time known cases. Some intra-patient variability in the manifestation of the imageability effect may thus be expected. The problem we are facing here, however, is not one of intra-patient variability, but one of varying manifestation within one patient.[4]

Since on both occasions the same testing material was used, one could be inclined to say this variability is caused by an unstable nature of the examined properties of words, the patient's fluctuating performances or both these factors. Diesfeldt (1990), however, when studying word imageability ratings in Dutch, found intergroup Pearson correlations of 0.81 for nouns, 0.92 for verbs and 0.64 for adjectives, thus suggesting that imageability scales might be reasonably reliable and stable. In comparing subjective word frequency estimations of 42 Dutch-speaking individuals (16 males, 26 females, mean age 18.7 years (s.d.: 0.82), mean Catell (form 3) IQ: 114.6 (s.d.: 13.71)) with objective frequency counts (Uit den Boogaart, 1975) we found Pearson correlations of 0.80 for nouns, 0.83 for verbs, 0.89 for adjectives, and 0.75 for function words. In a rather indirect way, the latter relatively high positive correlations point out that word frequency values, as well as imageability estimations, may be worked with as reliable measuring instruments. The only possible source of variability remains thus the patient's unstable quantitative performance profile. This means that the self-consistency of a patient's reading behaviour, which is considered by Morton and Patterson (1980) and Barry (1984) as a requirement for explanatory model construction, is to be questioned.

The shift from a non-significant performance to a significant one when the reading of function words is compared to the reading of content words may be understood by the same intra-patient variability. The figures in Table 5, however, could suggest the function word reading deficit is a more therapy resistent one (in our still agrammatic patient), since there seems to be improvement in the reading of all other word classes. The stability of our patient's aphasia, and more specifically, the low G-value we computed in comparing the reading success rates per word class, weakens the latter hypothesis.

If we now turn to the results of the FWA test, it becomes clear that L.G.'s associations differ considerably from those found in normals. The very significant smaller number of tangential responses is one very important factor in this pattern shift. If we accept a network lexicon (see Collins and Loftus (1975) who proposed a network model for semantic memory with a concept-word matching dictionary attached to it) rather than feature constructed model,[5] we may conclude, from these particular findings, that in the lexicon used by our patient during the FWA test there was significantly less lexical spreading activation.[6]

A second important difference between our patient's response pattern and that of normals consists of a significantly greater number of syntagmatic completions and bound morpheme completions in L.G. Since we concluded there is a deficit in the lexical activity, we may reasonably believe these two rather grammar-mediated response types to be compensatory strategies used when the lexicon cannot be accessed or sufficiently activated.

L.G.'s significantly lower number of 'attributive' responses is a third distinctive feature. In this type of response, lexical as well as sequential processing seem equally important, since the search has to yield a word that is semantically related to the stimulus word and at the same time probable to appear in a syntagma together with it. An explanation might be that in our patient there is a reduced capacity for combined lexical and sequential processing, a phenomenon well known in aphasia. The pathological increased number of responses in which it is obvious the stimulus has been misunderstood is another phenomenon probably due to our patient's aphasia. Idiosyncrasy of FWA responses has also been reported in aphasia (Gewirth *et al.*, 1984; Wyke, 1962).

What do these observations permit us to say about the semantic errors? The fact that the aphasic and deep dyslexic patient G.R. has been reported to give 'typically normal' FWA responses (Newcombe and Marshall, 1980), is all the more reason not to jump to generalizing conclusions. However, if we accept the traditional explanation for the occurrence of semantic errors, which claims there is an underlying selection problem, we have to conclude that in our patient the brain lesion affects two types of lexicons in two totally opposite ways, since in the lexicon(s) she uses for speech, reading and writing to dictation (three modalities in which semantic errors have been observed)[7] there is too much lexical material from which it is difficult to choose, and in the lexicon used during free word associating there is too little lexical material available. The possibility of such a bizarre consequence of a brain lesion should not be overlooked, but on the other hand there are several observations to be made which weaken its probability. Firstly, the papers of Buckingham and Rekart (1979) and Friedman and Perlman (1982) suggest that the nature and the occurrence of semantic errors are not task specific. Moreover, the accumulated literature on the subject, illustrates that several of the important symptoms of the deep 'dyslexic' complex might not be unimodal (Coltheart *et al.*, 1987). Thirdly, our findings in experiment 2 prove that, in our patient, there is no significant difference in frequency of semantic errors in two different word production tests. Therefore, we think, it is not absolutely necessary to conceive different types of lexicons.

Although being fully aware of the speculative nature of our reasoning, we would like to propose an explanation for the semantic errors in terms of a reduced spreading activation in the lexicon in which the patient's utterance results from a defective search. An advantage of the network conception is that, in being more dynamically oriented, it avoids the apparent difficulty the feature model interpretation has in explaining the semantic errors by a structural deficit, which is contradictory with the well-known variability in responses occurring in deep dyslexia. A second advantage of supposing such a spreading activation deficit would be that the sequential compensatory strategy observed in FWA can be held responsible for the 'associative' or 'syntagmatic' (Coltheart, 1980b) responses. The precise architectural delimitation of the suggested mechanisms and their consequences for a cognitive model remains a matter for further discussion.

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NOTES

[1] An advantage of this unit is that phenomena occurring during word completion and during complete word production can be treated as comparable. Moreover, apologizing sequences (*You know, sometimes I can't say it.*) can now be considered as one unit, which parallels the clinician's intuition that such utterances are in fact not real sentences but rather a special class of words.

[2] Consequently, the terms 'perseveration' (Gewirth *et al.*, 1984) or 'repetition' (Santo Pietro and Goldfarb, 1985), which have been used to designate all three mentioned categories as well as pure *stimulus word repetition*, have to be reserved for the latter phenomenon only. We will use the terms perseveration and intrusion as defined in Shindler *et al.* (1984). See also Bayles *et al.* (1985) for a conceptual and terminological review.

[3] During both examination sessions of 1988 and 1989, visual-then-semantic errors were not present in L.G.'s reading of isolated words. Only one occurrence of this type of error in L.G. has been noted.

[4] Although the frequency effect has not been listed in any of the two versions of the symptom complex of deep dyslexia (Coltheart, 1980a; Coltheart *et al.*, 1987) it has been suggested as possibly playing a role in the 'syndrome' by Patterson (1979, cited in Coltheart, 1980c). It has also been described in visual dyslexia (Marshall, 1984; Sasanuma, 1980) and surface dyslexia (Marcel, 1980; Marshall, 1984). The absence of a regularity effect rules out the possibility of surface dyslexia. The reading deficit cluster and the occurrence of semantic paralexias several years post onset (Patterson, 1982; Sartori *et al.*, 1984) permits us to situate L.G.'s reading on the symptomatology continuum (proposed by Glosser and Friedman, 1990 and by Laine *et al.*, 1990) closer to deep dyslexia than to phonological dyslexia, as well as they discredit the hypothesis of visual dyslexia.

[5] Although no real objections can be formulated against them, one has to admit that feature models of the lexicon have been criticized (De Groot, 1980; Melka Teichroew, 1989) and that the psychological reality of a feature organized semantic memory has been questioned (Collins and Loftus, 1975). Moreover, in refuting the associative theory as an explanation for the occurrence of semantic errors, Coltheart (1980b) seems to suggest that an associatively structured lexicon is accessed and governed by FWA rules only. His first objection (many semantic errors are not found in FWA norms) would be valid, if the aphasic or dyslexic patients' FWA would be normal ones. In our case (see Van Vugt and Paquier), as well as in others (Gewirth *et al.*, 1984; Wyke, 1962), this is not the case. Secondly, elements of series used as stimulus in a FWA task do not always yield the following element as a response as Coltheart (1980b) seems to think (see Deese's (1965) 'associative dictionary': eight → number; June → month, July, Summer). Thirdly, the definition response (e.g. pony → little horse) is not only produced by deep dyslexics during a reading task, but is also encountered in FWA samples of normals (De Groot, 1980).

[6] We use the term spreading activation without the negative or pathological connotation it has for Weigl and Bierwisch (1970, cited in Coltheart, 1980b). It is the process of searching through the network during which first the closest nodes are examined, then the ones situated somewhat further and so on.

[7] A reason for accepting a disturbance in the lexicon rather than in the semantic memory (knowledge of the real and mentally constructed worlds) may be found in the fact that deep dyslexics are reported to be able to define or circumscribe the target, without being able to utter it, and in their ability to rate self-confidence in the given response (Katz and Goodglass, 1990; Newcombe and Marshall, 1980).

REFERENCES

Albert, M. and Sandson, J.: 1986, 'Perseveration in aphasia', *Cortex* **22**, 103–115.

Barry, C.: 1984, 'Consistency and types of semantic errors in a deep dyslexic patient', in R. Malatesha and H. Whitaker (eds.), *Dyslexia, A Global Issue*, Martinus Nijhoff Publishers, The Hague, pp. 311–338.

Bayles, K., Tomoeda, C. and Kaszniak, A.: 1985, 'Verbal perseveration of demented patients', *Brain and Language* **25**, 102–116.

Buckingham, H. and Rekart, D.: 1979, 'Semantic paraphasia', *Journal of Communication Disorders* **12**, 197–209.

Clark, H.: 1970, 'Word associations and linguistic theory', in J. Lyons (ed.), *New Horizons in Linguistics*, Penguin Books, Harmondsworth, pp. 271–286.

Collins, A. and Loftus, E.: 1975, 'A spreading-activation theory of semantic processing', *Psychological Review* **82**, 407–428.

Coltheart, M.: 1980a, 'Deep dyslexia: A review of the syndrome', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 22–47.

Coltheart, M.: 1980b, 'The semantic error: Types and theories', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 146–159.

Coltheart, M.: 1980c, 'Deep dyslexia: A right hemisphere hypothesis', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 326–380.

Coltheart, M., Patterson, K. and Marshall, J. (eds.): 1980, *Deep Dyslexia*, Routledge & Kegan Paul, London.

Coltheart, M., Patterson, K. and Marshall, J.: 1987, 'Deep dyslexia since 1980', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, 2nd edition, Routledge & Kegan Paul, London, pp. 407–451.

De Groot, A.: 1980, *Mondelinge Woordassociatienormen, 100 Woordassociaties op 460 Nederlandse Zelfstandige Naamwoorden*, Swets & Zeitlinger, Lisse.

De Partz, M. P.: 1986, 'Re-education of a deep dyslexic patient: Rationale of the method and results', *Cognitive Neuropsychology* **3**, 149–178.

Diesfeldt, H.: 1990, 'Generaliseerbaarheid van voorstelbaarheidswaarden', *Nederlands Tijdschrift voor de Psychologie* **45**, 227–231.

Fodor, J. and Katz, J.: 1964, *The Structure of Language, Readings in the Philosophy of Language*, Prentice Hall, Englewood Cliffs.

Franz, S. J.: 1930, 'The relations of aphasia', *Journal of General Psychology* **3**, 401–411.

Friedman, R. and Perlman, M.: 1982, 'On the underlying causes of semantic paralexias in a patient with deep dyslexia', *Neuropsychologia* **20**, 559–568.

Galton, F.: 1879, 'Psychometric experiments', *Brain* **2**, 149–162.

Gewirth, L., Shindler, A. and Hier, D.: 1984, 'Altered patterns of word association in dementia and aphasia', *Brain and Language* **21**, 307–317.

Glosser, G. and Friedman, R. B.: 1990, 'The continuum of deep/phonological alexia', *Cortex* **26**, 343–359.

Goodglass, H. and Kaplan, E.: 1983, *The Assessment of Aphasia and Related Disorders*, Lea and Febiger, Philadelphia.

Huber, W., Poeck, K., Weniger, D. and Willmes, K.: 1983, *Der Aachener Aphasia Test*, Hogrefe Verlag, Göttingen.

Jung, C. and Riklin, F.: 1904/1973, 'The associations of normal subjects', in C. Jung (ed.), *Experimental Researches*, Routledge & Kegan Paul, London, pp. 3–196.

Kapur, N.: 1980, 'Recognition of word associates in semantic paralexia', *British Journal of Psychology* **71**, 401–405.
Katz, R. and Goodglass, H.: 1990, 'Deep dyphasia: Analysis of a rare form of repetition disorder', *Journal of Brain and Language* **39**, 153–185.
Kremin, H.: 1984, 'Comments on pathological reading behavior due to lesions of the left hemisphere', in R. Malatesha and H. Whitaker (eds.), *Dyslexia, A Global Issue*, Martinus Nijhoff Publishers, The Hague, pp. 273–310.
Laine, M., Niemi, J. and Marttila, R.: 1990, 'Changing error patterns during reading recovery: A case study', *Journal of Neurolinguistics* **5**, 75–81.
Marcel, T.: 1980, 'Surface dyslexia and beginning reading: A revised hypothesis of the pronunciation of print and its impairments', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 227–258.
Marshall, J.: 1984, 'Toward a rational taxonomy of the acquired dyslexias', in R. Malatesha and H. Whitaker (eds.), *Dyslexia, A Global Issue*, Martinus Nijhoff Publishers, The Hague, pp. 45–58.
Marshall, J. and Newcombe, F.: 1980, 'The conceptual status of deep dyslexia: An historical perspective', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 1–21.
Marshall, M., Newcombe, F. and Marshall, J.: 1970, 'The microstructure of word-finding difficulties in a dysphasic subject', in G. Flores d'Arcais and W. Level (eds.), *Advances in Psycholinguistics*, North-Holland Publishing Company, Amsterdam, pp. 416–426.
Melka Teichroew, F.: 1989, 'Remarques sur le stéréotype et le marqueur dans la théorie sémantique', *Cahiers de Lexicologie* **55**, 61–78.
Morton, J. and Patterson, K.: 1980, 'A new attempt at an interpretation, or, an attempt at a new interpretation', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 91–118.
Newcombe, F. and Marshall, J.: 1980, 'Response monitoring and response blocking in deep dyslexia', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 160–175.
Paquier, P., van Vugt, P., Bal, P., van Dongen, H. R., Parizel, P. M., Creten, W. and Martin, J.-J.: 1992, 'Deep dyslexia in a Dutch-speaking patient', *Aphasiology* **6**, 309–320.
Patterson, K.: 1982, 'The relation between reading and phonological coding: Further neuropsychological observations', in A. Ellis (ed.), *Normality and Pathology in Cognitive Functions*, Academic Press, London, pp. 77–111.
Randolph, C.: 1991, 'Implicit, explicit, and semantic memory functions in Alzheimer's disease and Huntington's disease', *Journal of Clinical and Experimental Neuropsychology* **13**, 479–494.
Raven, J. C.: 1958, *Standard Progressive Matrices*, Lewis & Co., London.
Salus, P.: 1980, 'Semantische Paraphasie und normales Wortassoziieren', in K. Gloning and W. Dressler (eds.), *Paraphasie, Untersuchungen zum Problem lexikalischer Fehlleistungen*, W. Fink, München, pp. 115–120.
Santo Pietro, M. J. and Goldfarb, R.: 1985, 'Characteristic patterns of word association responses in institutionalized elderly with and without senile dementia', *Brain and Language* **26**, 230–243.
Sartori, G., Barry, C. and Job, R.: 1984, 'Phonological dyslexia: A review', in R. Malatesha and H. Whitaker (eds.), *Dyslexia, A Global Issue*, Martinus Nijhoff Publishers, The Hague, pp. 339–356.
Sasanuma, S.: 1980, 'Acquired dyslexia in Japanese: Clinical features and underlying mechanisms', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 48–90.
Schifko, P.: 1977, *Aspekte einer strukturalen Lexikologie*, Francke, Bern.

Shallice, T. and Warrington, E.: 1980, 'Single and multiple component central dyslexic syndromes', in M. Coltheart, K. Patterson and J. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 119–145.

Shindler, A., Caplan, L. and Hier, D.: 1984, 'Intrusions and perseverations', *Brain and Language* **23**, 148–158.

Uit den Boogaart, P.: 1975, *Woordfrequenties in geschreven en gesproken Nederlands*, Oosthoek, Scheltema & Holkema, Utrecht.

Van Vugt, P. and Paquier, P.: 1992, 'Typically measurement of free word association responses', *Neuropsychologia* (submitted).

Wycke, M.: 1962, 'An experimental study of verbal association in dysphasic subjects', *Brain* **85**, 679–686.

H. KREMIN

APROPOS IMAGEABILITY

ABSTRACT. Experimental data concerning the writing performance of a brain-damaged patient which are at variance with unitary explanation (in terms of imageability and/or ease of prediction) for 'deep' patterns of performance in reading and writing are discussed.

INTRODUCTION

A 'deep' pattern concerning the treatment of isolated words – whether in reading aloud (resulting in 'deep dyslexia' (cf. Coltheart *et al.*, 1980)) or in writing from dictation (resulting in so called 'deep dysgraphia (cf. Howard and Franklin, 1989)) – is characterized by a typical pattern of performance: the production of semantic errors, an effect of concreteness with more errors being made to abstract words, and severe problems on function words and nonwords. In terms of information processing, this error pattern reflects treatment solely by the semantic pathway.

Several explanations have been advanced to account for this pattern of performance. Thus Morton and Patterson (1980) favor the view that several distinct functional lesions within the semantic pathway are responsible for the deficit: problems with concrete semantics, problems with abstract semantics and problems at the level of the linguistic processing mechanisms which are supposed to intervene during the treatment of closed-class words thus resulting in a 'multicomponent syndrome' (Shallice and Warrington, 1980).

However, there are other explanations for the noun/functor dissociation. On the one hand, it was argued – for example by Caramazza and Berndt (1978) – that function words do not have a specific semantic representation. On the other hand, it has also been argued that the distinction between open- and closed-class words may not be syntactic in nature but, rather, be a function solely of a difference in their relative degrees of imageability. The latter argument is moreover supposed to account for the overall word-class effect with nouns > adjectives > verbs > functors. This pattern was first described in GR, a deep dyslexic patient (Marshall and Newcombe, 1966, 1973) and subsequently confirmed for several other cases.

In the following sections I am going to discuss some data concerning the writing performance of GI, a deep dysgraphic patient (see Table 1 – from Kremin, 1989), with regard to the imageability quality attached to various kinds of stimuli. The patient produced some, albeit rare, semantic

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TABLE 1

Writing from dictation (percentage correct).

Concrete nouns:[a]	75%	(30/40)
Abstract nouns:[a]	25%	(10/40)
Verbs:	20%	(8/40)
Open-class words:[a]	48%	(12/25)
Closed-class words:[a]	8%	(2/25)
Regular words:[a]	58%	(29/50)
Irregular words:[a]	56%	(28/50)
Nonsense syllables:	0%	(0/20)
Presence of semantic errors	YES	

[a] Pairwise matched for frequency and number of letters.

paragraphias which were predominantly close synonyms of concrete words (e.g. coussin / cushion > oreiller / pillow; village village > hameau / hamlet; musulman / Moslem > arabe / Arab).

FIRST APROPOS ON IMAGEABILITY: VISUAL IMAGES

The study of visual imagery and image generation is at the core of recent psychological research as a result of the empirical and theoretical work of Paivio *et al.*. Paivio's dual coding theory explains cued recall "in terms of the joint activity of independent verbal and nonverbal (imaginal) systems. Recall depends partly on the capacity of the nonverbal system to generate composite images to pairs during study trials and to reintegrate those images to cue words during test trials" (Paivio *et al.*, 1988, p. 422). "The ease with which such images are generated and reintegrated depends partly on verbal to imaginal referential connections, which are more available for concrete than for abstract words" (op. cit., p. 422).

The ease with which words give rise to mental images has also been shown to be a powerful determinant especially of the reading performance of deep dyslexic patients (see Shallice, 1988). Note, however, that for at least one patient with deep dyslexia (Coslett *et al.*, 1985) the oral reading of concrete as opposed to abstract words is not statistically significant. Similarly, for patient HW (Caramazza and Hillis, 1990) the difference of errors in response to abstract words as compared to concrete words is minor (86% vs. 81% respectively). The patient produced however numerous semantic errors in oral reading (which was also clearly affected by a word's grammatical class) and was unable to read nonwords.

In the context of reading the degree of imagery usually refers to rated imageability, which is defined, following Paivio, explicitly in terms of the ease with which a word can evoke a mental image. Baddeley *et al.* (1982), however, pointed out that "the process whereby imageability influences readability is obviously a puzzle for any theory of reading" (p. 196).

If imageability is used as a strategy, a deep dysgraphic patient should do something like 'image the things described by the words you hear'. More specifically, studying the patient GI, we wanted to know to what extent he relies on a truly visual component while (or if) using imageability as a compensatory strategy. Thus the patient was asked to write from dictation various stimuli assumed to differ in their extent to which they might evoke a mental image: letters, digits, abbreviations, first names, proper names and (monosyllabic) nouns of high and low imagery.

Note that isolated letters and digits ought to be easily 'visualized' (they moreover belong to restricted sets). But note also that letters and digits have no 'meaning' attached to imagery. In contrast, abbreviations (like IBM) are series of letters which are meaningless in isolation but meaningful in combination. Supposedly one would not necessarily visualize the abbreviation but rather the corresponding meaning or referent (such as a computer). First names, on the other hand, bear no meaning and usually do not give rise to images. According to some theorists (Kripke, 1980) proper names are also meaningless labels. Experimental evidence from aphasiological research confirms that access to proper names (as compared to common nouns) can be selectively disrupted by brain damage (Semenza and Zettin, 1989). The items we chose for the purpose of this study – names of cities and of politicians – may, however, typically be visualized (on a map, through experience from television, etc.).

The results (see Table 2) show that GI wrote isolated letters and digits less well than both abbreviations and nouns of high imagery (13% and 20% as compared to 60%). The bad performance with isolated letters and digits therefore ought not be related to the fact that the stimuli are monosyllabic but, rather, to the fact that letters and digits do not convey meaning in spite of high imagery in terms of their correspondence to visual images. Indeed, the patient is well capable of producing even series of isolated letters, namely when they serve as a vehicle for meaning as in the case of abbreviations.

The difference between high and low imagery common nouns is – according to current interpretation – a reflection of the ease with which a word gives rise to imagery impression of its referent. GI's low performance on first names would also fit such interpretation. However, GI's low performance on first names (30% correct) contrasts with his relatively

TABLE 2

Writing from dictation (percentage correct).

			Imagery	Meaning
Letters	13%	(2/15)	+	–
Digits	20%	(2/10)	+	–
Abbreviations	60%	(6/10)	+	+
First names	30%	(3/10)	–	–
Proper nouns (1)				
(a) politicians	80%	(12/15)	+	+
(b) cities	80%	(8/10)	+	+
Monosyllabic nouns:				
(a) high imagery	60%	(6/10)	+	+
(b) low imagery	10%	(1/10)	+/–	+
Proper nouns (2)				
(a) with 'visual experience' (e.g. Kennedy, Belmondo, etc.)	51%	(13/25)	+	+
(b) without 'visual experience' (e.g. Cicero, Erasmus, etc.)	48%	(12/25)	–	+

good performance on proper nouns (80% correct). Notwithstanding the linguistic theory concerning proper nouns – which in fact is not without contradiction – I would therefore argue that GI writes first names badly since they do not convey meaning and/or imagery. The proper names tested, on the contrary, may convey meaning and/or imagery.

In order to disentangle the share of the visual or imagery component in this puzzle we decided to test once more the patient's writing from dictation of proper nouns. This time the list given concerned famous people whose name supposedly is associated with visual experience (e.g. Kennedy, De Gaulle, etc.) as opposed to famous people whose name is not (or hardly) associated with visual experience (e.g. Erasmus, Daedalus, Pericles, etc.). The results show that the patient wrote both types of proper names equally well (see Table 2), suggesting that imagery *per se* plays no substantial role in the patient's writing success.

One may however argue that imagery – if it has no explanatory power for success in writing – may still intervene as a variable to explain the error pattern. For example, one may expect omissions to typically occur more often with names which are not related to imagery. This is not the case. Indeed, the patient committed only three frank omissions (including one on Kissinger!). In all other cases GI made adequate verbal comments about the person without being able to write the corresponding name. In fact, the patient spontaneously complained that "the name gives a whole story but not the letters".

On the basis of the foregoing results and arguments I think indeed that proper nouns (when they are mediated via the cognitive system as in the case of deep dysgraphia) arouse 'stories' rather than images.

In this context, however, note also that with regard to the variable 'ease of predication' which Jones (1985) defined as "the ease of putting words into simple factual statements" (p. 4), both types of proper names administered for writing from dictation should not differ.

In summary, the observed error pattern in the patient's writing from dictation of various stimuli (letters, digits, abbreviations, names and common nouns) cannot be explained by his solely using the process of generating and naming mental images as a strategy for word production.

SECOND APROPOS ON IMAGEABILITY: WORD-CLASS EFFECT

Both the imageability explanation and the ease-of-predication model are attempts to produce a unitary functional account for a deep pattern of performance. Both attempts resemble each other in that they view deep performances as a reflection of properties rather than deficits of the semantic pathway. Jones (1985) claims that the "ordering observed among different syntactic categories is a reflection of the ease with which they summon matching predicates" (p. 9). Jones collected ease-of-predication scores from normal subjects and supported the hypothesis that the ease of predication scores for different syntactic classes of words vary in the same way as the ease of reading these words by deep dyslexic patients, that is nouns > adjectives > verbs > function words. Unfortunately, Jones also found a very high correlation between imageability and ratings of the ease with which predicates of a word are summoned. In fact, in only 12 of 125 nouns rated were the differences between imageability and ease of predication score highly significant.

So far, however, the investigation of neuropsychological disorders of lexical processing does not seem to confirm unitary processing hypotheses. On the one hand, Allport and Funnell (1981) provided suggestive experimental evidence for the notion that the part-of-speech-effect between nouns and verbs (in five patients with deep dyslexia) may be due to uncontrolled imageability values of the stimuli. And, more recently, Howard and Franklin (1989) found that their deep dysgraphic patient's writing from dictation does not demonstrate that there is a difference in performance neither between content and function words, nor between nouns and verbs, once imageability is controlled. On the other hand, Caramazza and Hillis (1991) reported the performances of two patients (showing no concreteness or abstractness effect on controlled lists neither in reading nor in writing from dictation) with a true grammatical class deficit of verb production in oral and written tasks.

Because of the contradictions in the literature with regard to the effect of imageability on the performance of patients relying exclusively on the use of the lexical semantic pathway for word production, we explored a possible part-of-speech-effect in GI's writing from dictation of nouns and verbs. Imageability ratings on verbs are not available in French. In order to avoid possible artifacts of list composition we decided to study GI's writing from dictation of high imagery nouns (which were object picture names) and high imagery verbs (which were action picture names). Thirty nouns and thirty verbs were matched pairwise for frequency (Julliand *et al.*, 1970). The action names were taken from the pool of pictures used by McCarthy and Warrington (1985). It is evident that they are highly imageable since they are easily and unambiguously represented by line drawings. GI wrote all nouns correctly from dictation but only 60% of the verbs.

We moreover investigated GI's auditory comprehension of nouns and verbs by means of a pictorial multiple choice task: one spoken word was presented and GI had to point to the corresponding picture from an array of four pictures where the distractors were closely related semantically. The set included the stimuli from dictation plus twenty more nouns and verbs. With both verbs and nouns GI scored 88% correct. He thus understood object and action pictures names equally well in spite of his selective deficit in writing action picture names from dictation.

In order to investigate possible problems of GI's written word production related to output from semantics, we furthermore studied the patient's written naming of object and action pictures. GI named 116 out of 120 object pictures. The patient's written naming was also tested on 55 actions taken from McCarthy and Warrington (1985): 25 action names were solicited by simultaneous presentation of two different drawings depicting the same action; the naming of another 30 actions was studied by presenting one single action picture. The patient's written naming of verbs did not benefit from the two-picture condition: with one picture he scored 50% correct, with two pictures 40%. Overall GI scored 45% correct in naming action pictures as compared to 97% correct on object pictures. The selective deficit in the retrieval of action names was, however, not limited to written output since oral action picture naming was similarly disturbed.

SUMMARY AND COMMENTS

The foregoing results and arguments are at variance with unitary accounts of 'deep performance' in terms of 'imageability' and/or 'ease of predication' theories. Neither can the patient's overall writing performance be explained by the sole use of visual images nor can the observed part-of-speech-effect be accounted for by a unitary explanation. Indeed, GI's deep dysgraphia seems to result from various functionally distinct lesions in the course of information processing while writing from dictation (cf. Kremin, 1986; in preparation):

1. A central disturbance of abstract semantics (resulting in comprehension deficits given both visual and auditory input);
2. A central disturbance at the linguistic processing mechanisms responsible for the treatment of function words (resulting in comprehension deficits given both visual and auditory input);
3. Specific problems, of accessing (even concrete) semantics through auditory input only;
4. A selective but general deficit of verb retrieval, as opposed to relatively spared retrieval of nouns, at the level of the output lexicons and/or access from semantics which results in lexicalization deficits in oral and written naming as well as in repetition and writing from dictation;
5. Impairment of the nonlexical phonologic conversion system in which phonemes are converted into letters, which results in total inability to write nonsense syllables.

We thus agree with Baddeley *et al.* (1982) that "despite the fact that imageability is a potent variable, it has virtually no explanatory power" (p. 196) for the patients' performance in specifically disturbed reading or writing of isolated words. Deep dysgraphic writing as well as deep dyslexic reading may indeed be multicomponent syndromes – in an even broader sense, however, than is usually touched upon.

Instead of a conclusion, I would like to underline some characteristics of GI's faulty production of verbs. A *post hoc* item analysis reveals that the patient's writing from dictation benefits from lexically and semantically unambiguous verb/noun relations – such as LIRE (to read) which, in French, has morphological similarity with LIVRE (book); PLONGER (which corresponds to PLOGEON), etc. In the case of morpholexical similarity between verb and noun the patient yields about 50% correct productions. In the absence of such morpholexical relations – such as GRIMPER (to climb) une ECHELLE (a ladder), SOULEVER un POIDS, etc. – GI's performance drops to 6%.

This view seems to be substantiated by error analysis of written naming. The patient's written production often resulted in neologistic derivations from existing nouns, e.g. PLEURER (to cry) written as LARMER*: supposedly derived from *la larme* (the tear). The patient's writing may also result in existing but inadequate derivations from nouns, e.g. SOUFFLER (to blow) written as BOUGER (to move), supposedly derived from *la bougie* (the candle).

It is evident that such a performance pattern cannot be explained in terms of imageability strength of the stimulus word to be written. It rather seems to substantiate the view proposed by Gentner (1981) that differences between nouns and verbs stem in part from a more basic cognitive distinction that is correlated with the noun–verb distinction: the distinction between object-reference concepts and relational concepts. In this view object-reference concepts are typically lexicalized as concrete nouns (such as *dog*) whereas relational concepts from the same concrete level are typically lexicalized as verbs (such as *bark*). Note, however, that many concepts can be lexicalized either as nouns or verbs, e.g. *He put a cover on it = He covers it.*

It seems as though the patient GI uses the principle of (a possible) morpholexical correspondence between noun, and verb as a compensatory strategy in order to overcome his severe deficit in retrieving action names. Unfortunately this principle is not a general one and therefore his retrieval of action names often goes wrong resulting in faulty lexicalizations.

Finally, since this compensatory strategy of 'derived' lexicalization for word retrieval cannot be applied to surnames, the patient's errors in the writing from dictation of proper names (via the semantic route) mainly results in frank omissions which are, however, accompanied by adequate verbal comments.

REFERENCES

Allport, A. and Funnell, E.: 1981, 'Components of the mental lexicon', *Philosophical Transactions of the Royal Society of London* **B295**, 397–410.

Baddeley, A. D., Ellis, N. C., Miles, T. R. and Lewis, V. J.: 1982, 'Developmental and acquired dyslexia: A comparison', *Cognition* **11**, 185–199.

Caramazza, A. and Berndt, R. S.: 1978, 'Semantic and syntactic processes in aphasia: A review of the literature', *Psychological Bulletin* **85**, 898–918.

Caramazza, A. and Hillis, A. E.: 1990, 'Where do semantic errors come from?', *Cortex* **26**, 95–122.

Caramazza, A. and Hillis, A. E.: 1991, 'Lexical organization of nouns and verbs in the brain', *Nature* **349**, 788–790.

Coltheart, M., Patterson, K. and Marshall, J. C. (eds.): 1980, *Deep Dyslexia*, Routledge & Kegan Paul, London.

Coslett, H. B., Rothi, L. G. and Heilman, K. M.: 1965, 'Reading: Dissociation of the lexical and phonologic mechanisms', *Brain and Language* **24**, 20–35.

Gentner, D.: 1981, 'Some interesting differences between verbs and nouns', *Cognition and Brain Theory* **4**, 161–178.

Howard, D. and Franklin, S.: 1989, *Missing the Meaning? A Cognitive Neuropsychological Study of Processing of Words by an Aphasic Patient*, MIT Press, Cambridge, MA.

Jones, G. V.: 1985, 'Deep dyslexia, imageability, and ease of predication', *Brain and Language* **24**, 1–19.

Julliand, A., Brodin, D. and Davidovich, C.: 1970, *The Frequency Dictionary of French Words*, Mouton, The Hague.

Kremin, H.: 1989, 'Case study of a patient with deep dysgraphia with special attention to the noun/verb distinction', paper presented at the *International Conference on Cognitive Neuropsychology,* The British Psychological Society, Cognitive Psychology Section, Harrogate, England, July 1989.

Kremin, H.: 'Case study of a patient with surface dyslexia and deep dysgraphia', in preparation.

Kripke, S.: 1980, *Naming and Necessity*, Basil Blackwell, Oxford.

Marshall, J. C. and Newcombe, F.: 1966, 'Syntactic and semantic error in paralexia', *Neuropsychologia* **4**, 169–176.

Marshall, J. C. and Newcombe, F.: 1973, 'Pattern of paralexia: A psycholinguistic approach', *Journal of Psycholinguistic Research* **2**, 175–199.

McCarthy, R. and Warrington, E. K.: 1985, 'Category specificity in an agrammatic patient: The relative impairment of verb retrieval and comprehension', *Neuropsychologia* **23**, 709–727.

Morton, J. and Patterson, K.: 1980, 'A new attempt at an interpretation, or, an attempt at a new interpretation', in M. Coltheart, K. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 91–118.

Paivio, A., Clark, J. M. and Khan, M.: 1988, 'Effects of concreteness and semantic relatedness on composite imagery ratings and cued recall', *Memory and Cognition* **16**, 422–430.

Semenza, C. and Zettin, M.: 1989, 'Evidence from aphasia for the role of proper names as pure referring expressions', *Nature* **342**, 678–679.

Shallice, T.: 1988, *From Neuropsychology to Mental Structure*, Cambridge University Press, Cambridge, U.K.

Shallice, T. and Warrington, E. K.: 1980, 'Single and multiple component central dyslexia syndromes', in M. Coltheart, K. E. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 119–145.

PREBEN KIHL

LEXICAL AGRAPHIA IN A YOUNG MAN WITH MULTIFOCAL BRAIN-INJURIES: A DANISH CASE STUDY

ABSTRACT. The study describes a young, Danish lexical agraphic's history of illness and the medical, psychological and speech-therapeutic findings. The subject's brain damage is multifocal, but primarily right sided judged by the severe behavioral and gnostic symptoms. His language is moderately paraphasic. Formal evaluation of the subject's reading and spelling at the age of 21 reveals that his reading is comparatively correct and slow, but his spelling is defective and affected by orthographic irregularity, while his ability to segment words is preserved. An analysis of the spelling errors in the subject's many self-composed essays demonstrates that his spelling in 30% of all his written words is almost exclusively phonemic. This result is discussed in the light of the complex Danish orthography and in terms of e.g. Danish school children's patterns of spelling errors. This leads to a reconsideration of the concept of 'phonologically plausible spelling error' in other studies of lexical agraphia. Finally, the relation between the subject's method of spelling, his paraphasia, his reading and the loci of brain damage is discussed.

INTRODUCTION

Within the framework of cognitive information-processing models two parallel systems for spelling, both oral and written, have been proposed (Deloche and Andreewsky, 1982; Ellis, 1984; Patterson *et al.*, 1985; Roeltgen, 1985). The one is the phonological spelling system (Beauvois and Dérousné, 1981; Hatfield and Patterson, 1983; Roeltgen and Heilman, 1984) the other, the lexical system (Ellis, 1982; Margolin, 1984; Patterson, 1988; Rapcsak and Rubens, 1990). Brain damage in persons who have learned to write apparently produces different disruptions to these systems. Injury to the phonological system leads to phonological agraphia (Bolla-Wilson *et al.*, 1985; Roeltgen *et al.*, 1983; Shallice, 1981) while injury to the lexical system produces lexical agraphia (Beauvois and Dérousné, 1981; Deloche *et al.*, 1982; Hatfield and Patterson, 1983; Roeltgen and Heilman, 1984; Shallice and Warrington, 1980). The hallmarks of lexical agraphia are impaired ability to spell orthographically irregular words which results in phonologically plausible spelling errors, but preserved ability to segment and spell nonsense words. The syndrome is interpreted as the written counterpart to surface dyslexia.

When the spelling behavior of S.L., the lexical agraphic of this study, is interpreted within the dual route approach to the acquired, linguistic, agraphias, his way of spelling seems to demand a new component in the

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sublexical assembly process in a compromise spelling model like Ellis' (1988). Apparently, the structure of the subject's spelling errors predicts a component that takes phonological segments as its input and compares these segments with letter-names (or -sounds). When a suitable match has been found, the relevant letter-name is either pronounced as oral spelling or fed to a mechanism that converts letter names to letter-shapes on the way to the so-called grapheme level. A theoretical framework with two spelling routes thus provides a reasonable model within which the subject's spelling method may be interpreted.

Whether this statement holds good of single process models (Glushko, 1979; Castles and Coltheart, 1993; Monsell *et al.*, 1992) such as the parallel distributed processing (PDP) network implemented by Seidenberg and McClelland (1989) is less clear. As a PDP-network perhaps stores letter-to-sound regularities more robustly than exceptional patterns, such a network might, as a result of incidental damage, produce the type of error characteristic of surface dyslexia (Patterson *et al.*, 1989). It is possible, therefore, that a connectionist or analogy spelling process model might also generate the error patterns of older lexical agraphics whose spelling errors mirror the sound-to-letter frequencies of their language as in Baxter and Warrington's (1987) study. In general, however, the misspellings of the young subject of this study conflicts with the sound-to-letter frequencies of several, perhaps all of the Danish sound-to-letter systems. The evidence for this claim is presented in the two final sections of this article.

To my knowledge, descriptions of one French and nine English patients suffering from lexical agraphia have been published (Baxter and Warrington, 1987; Beauvois and Dérousné, 1981; Goodman-Schulman and Caramazza, 1987; Rapcsak *et al.*, 1988; Roeltgen and Heilman, 1984; Rothi *et al.*, 1987). The associated symptoms vary, but nine of the patients had one type of aphasia or another, eight are reported to have various reading disorders, while about half of the population had ideomotor apraxia and some signs of Gerstmann's syndrome. One patient had no other symptoms than the lexical agraphia (Rothi *et al.*, 1987). In general, the studies of Roeltgen *et al.* (1983, 1984) indicate that lexical agraphia is correlated with lesions in the region of the posterior angular gyrus.

The present study describes a right handed young man, S.L., with comparatively pure and isolated lexical agraphia. His brain damage is multifocal and predominantly right sided judged by the behavioral symptoms and neurological findings. He is slightly paraphasic with little alexia and with neither ideomotor apraxia nor Gerstmann's syndrome. The patient is young, from 13 to 21 years old during the investigation, compared with other published case of lexical agraphia in which the mean age is 59 years, range 24–86. He had just learned to read and write, and when he lost this ability he had to relearn it. Furthermore, he became an essay writer, a rare feat among lexical agraphics. As Danish orthography is very irregular compared with many alphabetic writing systems (Molbæk Hansen, 1983), this challenge to a lexical agraphic helps to clarify what is preserved and what is missing in his spelling.

Information about the medical, speech-therapeutic and psychological findings at the age of 13 to 15 were obtained from the general county hospital of Copenhagen, Gentofte. Medical examinations and language evaluation at the age of 21 were performed by physicians and speech-therapists at the general county hospital of Funen, Odense. The formal reading and spelling evaluations took place in the subject's home, and he himself permitted his essays to be used in the present study.

CASE REPORT

The subject, who was 21 years old at the time of investigation, suffered from the consequences of a severe cranial trauma following a traffic accident at the age of 13. Pneumo-encephalography one and a half month after the accident showed extension of the lateral ventricles and hydrocephalus (Figure 1).

EEG five months after admission was highly abnormal with diffuse activity above the right hemisphere, damping of dominant activity and an epileptic focus frontally to the right. S.L. improved well during the next six months, especially left hemisphere functions including speech and right arm, and was discharged from hospital one year after the accident and placed in a school for brain damaged children. Further neurological examinations showed multifocal lesions with right-sided predominance, left-sided visual neglect, facial, visual and tactile agnosias, severe space, directional and time-disorders, constructive apraxia, learning and short-time memory problems. His performance was also characterized by perseveration, 'Witzelsucht' or frontal damage, slight left-sided paralysis and poorly coordinated walk. Speech was characterized by moderate dysarthria and verbal paraphasia. Psychological tests between 14 and 19 years of age corresponded to the neurological findings. There was, for example, a very defective score on the WISC block design, jig-saw puzzle and picture arrangement sub-tests (age-scaled scores = 1, 2 and 3) and on the Frostig and Bender tests. On the other hand, the score on auditory and verbal sub-tests of WISC and ITPA was from low average to average. At the age of 21 renewed neurological examination indicated some recovery. There was, for example, only slight constructive apraxia as measured by the Bender test. CT-scanning, however, showed unchanged severe dilation

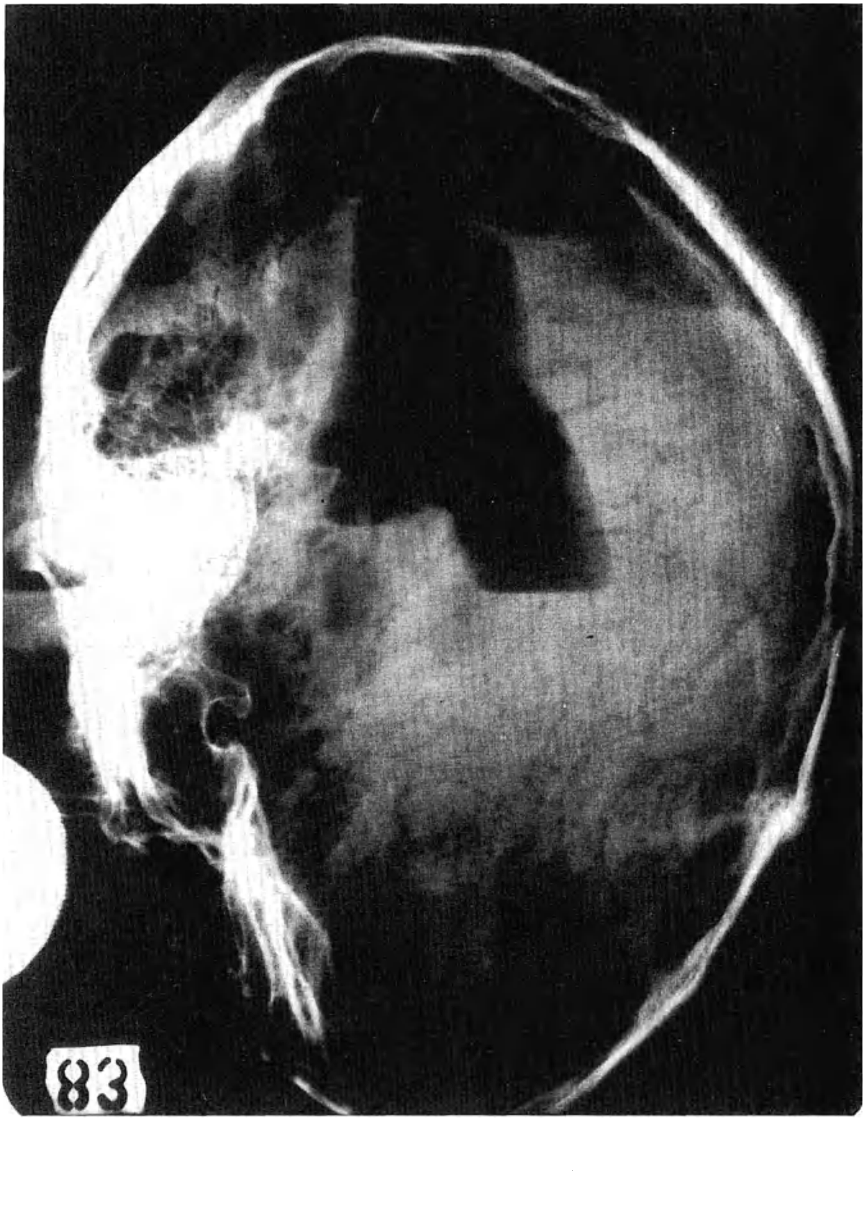

Fig. 1. Pneumo-encephalogram, S. L., 13 years.

of the ventricle system, a hypo-dense area in the right hemisphere and pronounced calcification of falx cerebri (Figure 2).

Speech-therapeutic examination presented the following results: Slight expressive aphasia with reduced word-mobilization and idiomatic functions; no dysarthria and impressive aphasia; moderate reading, writing and arithmetic difficulties.

FORMAL READING AND SPELLING EVALUATION

In addition to the tests in the case report, the patient at the age of 21 was subjected to a battery of reading and writing tests. The results are presented in tabular forms below.

Some tests had to be constructed because they did not exist as standardized Danish tests. In these tests the frequency and length of the test words were controlled by means of the frequency counts of Maegaard and Ruus (1981). The test with concrete and abstract nouns was designed by having 20 adults evaluate 80 nouns on a five point scale, whereupon the best 20 words of each type was used. The lists with nonsense words were constructed on the basis of Thorsen and Thorsen's survey of Danish consonant-clusters (1985, pp. 142–144). The degree of regularity in the reading and spelling tests consisting of real words within the same frequency range was calculated by multiplying the number of sounds with two or more spelling possibilities in a word with the number of their alternative spellings based on the sound-to-letter relations of Danish and on Noesgaard's (1945) study of Copenhagen school children's spelling errors. In the tables and the examples in the text the phonological transcriptions are a type-writer modified version of the International Phonetic Alphabet. In particular, it should be noted that consonantal /r/ is written as R, the semi-vowel /r/ as r, and that vowel allophones and stress are not indicated. The subject speaks the dialect of the island of Funen. Spelling errors are capitalized.

None of the error differences in Table 1 are statistically significant. The main conclusion to be drawn from Table 1 is negative. With certain reservations the functions tested are preserved and the error figures small in relation to the standardizations and to the error percentages of the alexia literature (Deloche and Andreewsky, 1982; Marshall and Newcombe, 1973; Patterson, 1981; Sasanuma, 1984; Shallice and Warrington, 1980). For example, in the first test of Table 1 S.L. reads 108 words in four minutes in the standardized reading aloud text for 7th grade. This corresponds to a t-value for 6th grade May of 25, which cuts off the 0.6 percentile in the low end of the scale of the 1969 standardization. On the other hand, the percentage of error in the same test is 3 corresponding to a t-value of

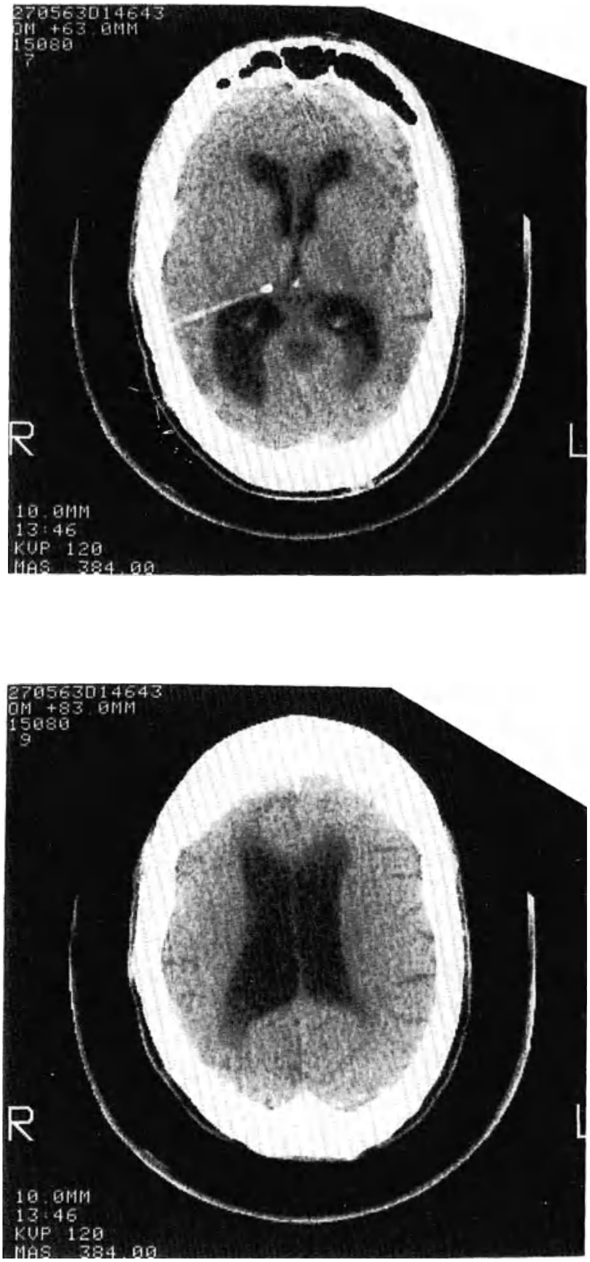

Fig. 2. CT-scanning, S.L., 21 years.

TABLE 1

Reading aloud, letter and sentence understanding tests, S.L., 21 years.

	Time in minutes	Percentage of errors	Examples of errors
Standardized text-reading (3rd, 5th and 7th grade) Standardized word-reading (2nd and 4th grade)	below average average in comparison to standardization (see comment)	above average average in comparison to standardization (see comment)	"all" "alle" /alə/ > /lilə/, "close" "tæt" /tεd/ > /tød/, "least" "mindste" /mensdə/ > /mesdə/, "bad" "slet" /slεd/ > /sle:d/, "uncle" "onkel" /ɔŋ?gl/ > /ɔŋ?kl/
40 verbs	2.15	7.5	"play" "lege" /la+jə/ > /legə/ "crept" "krøb" /kRø?b/ > /kRø?p/
40 adjectives	2.11	10	"worst" "værste" /værsdə/ > /vε:sdə/
40 function words	2.03	12.5	"for" "thi" /ti/ > /di/
40 nouns (control of average word-length only)	2.20	0	
20 concrete nouns	1.15	0	
20 abstract nouns	1.14	0	
Nonsense words: 20 four-letter words	 1.37	 10	"koln" /klo?n/ "bløs" /pløs/ "vije" /va+:jə/
20 five-letter words	1.49	15	"intre" /entRa/ "flæsb" /flæbs/
40 five-letter regular words	 4.12	 10	"broad" "brede" /bRæ:ð̃ə/ > /bRæ?də/
40 five-letter irregular words	 4.42	 10	"blind" "blind" /blen?/ > /blin?/
24 capital letters 24 small letters	 1.33	 6.25	"b" "p" "I" "l" "N" "z"
Matching of capital and small letters		0	
Standardized sentence understanding	average 2nd grade May	average 2nd grade May	

70, which is above the average for 6th–7th grade. This kind of slow, but relatively error free reading performance continues in the reading aloud of single words, of nonsense words and of letters. The overall percentage of reading errors in coherent tests is 2 (the first half of the first test in Table 1), while the error percentage in all tests consisting of single words is 8 (including the first test in Table 2).

Consequently, S.L.'s decoding function in reading is relatively normal compared with that of surface dyslexics. Sasanuma (1980), Deloche and Andreewsky (1982) found that surface dyslexics have serious problems with the reading aloud of sentences, which does not cause S.L. any problems. Sensitivity to word regularity is an important symptom of the surface dyslexic (Holmes, 1978; Marshall and Newcombe, 1973), but like the patients of Roeltgen and Heilman (1984) and Rapcsak *et al.* (1988) the reading of irregular words has no influence on S.L.'s behavior compared with his reading of regular words. Other dimensions such as word length (Sasanuma, 1980; Shallice and Warrington, 1980) and degree of abstraction of nouns (Marshall and Newcombe, 1973; Sasanuma, 1980), to which surface dyslexics have reacted, were similarly without influence.

The error differences shown in Table 2 between regular and irregular words and between four- and five-letter nonsense words are significant at the 0.01 level (chi square = 22.87 and 22.27 > 6.63). In general, the spelling errors of Table 2 are of the same kind as the spelling errors in the essays of the next section. The subject is able to pronounce words spelled to him, to copy a printed text and to read his own copy aloud, to write words flashed to him on a card, and to spell orally words said to him, both nonsense words and real words. On the other hand, homophones and the spelling regularity of real words influence his behavior in a way comparable to the behavior of other lexical agraphics (Rapcsak *et al.*, 1988; Roeltgen and Heilman, 1984).

AN ANALYSIS OF SPELLING ERRORS IN THE ESSAYS OF S.L. FROM AGE 16 TO 19

While the subject is a fair reader, his spelling is influenced by his brain damage. His spelling in the tests of Table 2 and especially in a series of independently written essays is quite original. He wrote these exercises for his teacher, but also in an effort to come to terms with his own emotional and sexual problems caused by his handicap. The percentage of spelling errors in ten essays of 2934 words in all with 881 spelling errors amount to 30% and about 92% of the errors are phonemic errors in orthographically irregular words.

TABLE 2

Spelling- and writing tests, S.L., 21 years.

	Time in minutes	Percentage of errors	Examples of errors
Standardized pronunciation of 28 spelled out words		10.7 2nd grade April–June	"they" "de" /di/ > /de/ "think" "mene" /me:nə/ > /mi:nə/ "paw" "poten" /po:dn/ > /pΛdn/
Copying 37 words	5	24.3	same type of error as in essays, "to" "til" TEL
Reading aloud the copy	1.12	0	
Writing of 10 flash card words		10	same type of error as in essays, "found" "fandt" FANT
Spelling aloud: 25 easy words	2.25	12	"leg" "ben" PEN
Homophone writing to dictation: 15 homophones in sentences		47	"had/hate" "havde/hade" /ha:ðə/ HADE
Standardized oral spelling: 30 words		20, May 5th grade	"stole" "stjal" STJALT
20 nonsense words		40, August 3rd grade	"slirk" CLIRK "kvangst" KVANSK
Oral spelling: 20 regular five-letter words		15	Same type of errors as in essays
20 irregular five-letter words		55	e.g. "to death" "ihjel" IJÆL
Oral spelling of nonsense words: 20 four-letter words		10	/lerv/ LEVD
20 five-letter words		45	/Rærgt/ RÆGT

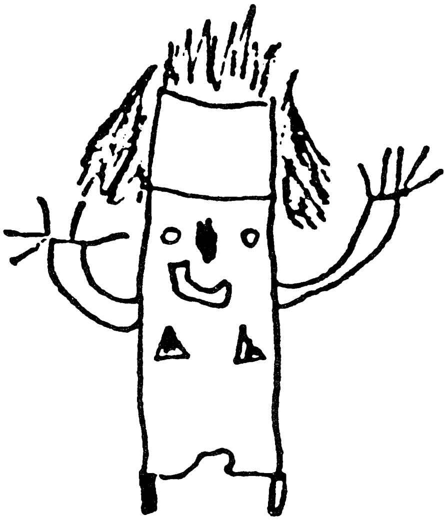

Fig. 3. "A pretty girl", S.L., 17 years.

In order to provide an impression of these essays, a specimen from an essay written at the age of 17 is presented below. The spelling errors are capitalized in the Danish version. The accompanying drawing by S.L. illustrates the story and the discrepancy between his defective visual-constructional abilities and his language abilities as in the story.

". . . opleve flere SKØNE	". . . experience more beautiful
syn og det kom jeg	sights and that I
skam OSE TEL men på	certainly also did but at
et tidspunkt tog jeg	a certain time I began
og SVØMEDE op mod SANET	to swim towards the sand
og tog og SLAPEDE LET A	and began to relax a little
og da solen var ved og	and when the sun was about to
gå ned tog jeg tøjet på	set I put my clothes on
for at BEGI mig hjemad	to go home
og da jeg var KOMET hjem	and when I had come home
kom min nabo END TEL MEG	my neighbour came up to me
for og ENVITERE mig på	to invite me in for
en tår KAFE og det tog	a cup of coffee and that
jeg imod og FULTE efter	I accepted and followed
men DI HADE OSE lavet	but they had also made
en LILE SOLKRÅ og der	a small sun-corner and there
SAGE hun A jeg godt MÅTE	she said that I was allowed
SÆTE mig så kom hun	to sit down then she would come

straks med en tår KAFE og
da jeg PLUSELIG SKULE TEL
og TA min TREJE tår slog
det END i mig A det LINEDE
HIN jeg så på STRANEN
og så SMILTE vi BEGE to
Ja jeg tror A det var A
CINERTHED hun smilede . . . "

soon with a cup of coffee and
when I suddenly was about to
take my third cup it struck
me that she looked like
the girl I saw on the beach
and then we both smiled
Yes I think it was because of
shyness she smiled . . . "

The spelling errors of the essay are analysed below. The phonological transcriptions are of modern standard Danish.

English translation	Danish orthography	S.L.'s errors	Phonological transcription	Interpretation of errors
beautiful	skønne	SKØNE	/sgœnə/	phonemic error
also	også	OSE	/ʌsə/	phonemic error
to	til	TEL	/tel/	phonemic error
swim	svømme	SVØME	/svœmə/	phonemic error
the sand	sandet	SANET	/sanəð/	phonemic error
relaxed	slappede	SLAPEDE	/slabəðə/	phonemic error
a little	lidt	LET	/led/	phonemic error
off	af	A	/aʔ/	phonemic error
go	begive	BEGI	/begiʔ/	phonemic error
come	kommet	KOMET	/kʌməð/	phonemic error
up	ind	END	/enʔ/	phonemic error
me	mig	MEG	/ma+j/	hypercorrection
invite	invitere	ENVITERE	/enviteʔɐ̯/	phonemic error
coffee	kaffe	KAFE	/kafə/	phonemic error
followed	fulgte	FULTE	/fuldə/	phonemic error
they	de	DI	/di/	phonemic error
had	havde	HADE	/ha:ðə/	phonemic error
small	lille	LILE	/lilə/	phonemic error
sun-corner	solkrog	SOLKRÅ	/solkRɔʔ/	phonemic error
said	sagde	SADE	/sa:a/	phonemic error
was allowed	måtte	MÅTE	/mʌdə/	phonemic error
sit	sætte	SÆTE	/sɛdə/	phonemic error
suddenly	pludselig	PLUSELIG	/plusəli/	phonemic error

The phonemic spelling method is apparent. This way of spelling is not only characteristic of this essay specimen, but appears in S.L.'s writings from approximately one and a half years after the accident up to his 21st year. That the brain damage caused the spelling errors is attested to by almost flawless exercises written by him in the fifth grade at the age of 12.

A comment on the concept of phonemic error versus other types of error and on the analysis of the subject's spelling errors is in order. Phonemic errors are defined here as a one-to-one correspondence between the transcribed sound in the target word and the incorrect letter-name or letter-sound such as "little" "lidt" /led/ LET and "jump" "hop" /hʌb/ HOB.

Examples of this type of phonemic error from the essay are TEL, LET, END, ENVITERE, DI, HIN, SOLKRÅ. Only vowel-to-letter-sound examples are given here, but many examples of consonant-to-letter errors occur in other essays, e.g. "hedge" "hæk" HÆG, "cup" "kop" KOB, etc. An important case of phonemic errors in the Danish spelling system is the one-to-one correspondence between no sound and no letter, even if the orthography requires a letter, e.g. the silent 'd'- and 'h'-letters in "fat" "fedt" /fed/ FET and "if" "hvis" /ves/ VIS. Examples of this type of error in the essay are LE(D)T, A(F), BEGI(VE), HA(V)DE, SOLKRÅ(G), SA(G)DE, PLU(D)SELIG, and the like. Another frequently occurring spelling error of the silent-letter type is the omission of one of the two consonant-letters for the consonant in the sound-group short vowel + consonant + schwa, e.g., "small" "lille" /lilə/ LILE, or the emission of the 'd' after short vowel + l/n/r + glottal stop as in "fall" "fald" /falʔ/ FAL. Examples of sound complex errors from the essay are SKØN(N)E, SVØM(M)EDE, SLAP(P)EDE, KOM(M)ET, KAF(F)E, SKUL(L)E (and "man" "mand" MAN, "mild" "mild" MIL as examples of errors in glottal stop groups).

These are the main possibilities of phonemic misspellings in the Danish spelling system. Apart from muddled spelling or mix up on the spelling process, the other main type of spelling error in Danish may be called hypercorrection. Hypercorrections may be defined as the opposite of phonemic errors, but still within the Danish spelling system, i.e. when the letter name does not correspond to the sound, but could have been right, e.g., "farmer" "bonde" /bɔnə/ BUNDE, or when a silent letter is written in a sound context, where it might have been rightly placed, e.g. "along" "hen" /hɛnʔ/ HEND. To illustrate the distinction between phonemic errors and hypercorrections, the following examples show some typical Danish spelling errors in connection with the short vowel /ɛ/ and the silent 'd'-letter after glottal stop.

"horse"	"hest"	/hɛsd/	HÆST
"guest"	"gæst	/gɛsd/	GEST
"fall"	"fald"	/falʔ/	FAL
"hall"	"hal"	/halʔ/	HALD

The short vowel /ɛ/ is misspelled in two different ways in a particular sound context and the silent 'd' is wrongly deleted or added in another sound context in accordance with the main and appropriate options of the Danish spelling system. The patient of this study in general only utilizes the first possibility, i.e., spells /ɛ/ as æ – probably because sound and letter correspond to each other – but not /ɛ/ as 'e' even though the 'e'-letter is the more frequent. In the same way the subject only discards the silent 'd', never adds is. But words with 'd' after short vowel + l + glottal stop are more frequent in Danish than such words without 'd' (Holmboe, 1978).[1] That this way of spelling is not obvious is confirmed by studies, e.g. the large Noesgaard survey (1945) and Kihl (1986, 1988), in which normal Danish school children commit about 40% hypercorrections, 55% phonemic errors and 5% other errors depending on factors like age and the sound-to-letter system in question.

When the subject's 881 spelling errors in the ten essays of 2934 words are categorized as either phonetic errors, hypercorrections or muddled spelling, the relative distribution – the percentage of each type of error – is as follows: 92.4% phonetic errors, 5.3% hypercorrections, 2.3% muddled spelling.

DISCUSSION

Other research (Baxter and Warrington, 1987; Beauvois and Dérousné, 1981; Ellis, 1984, p. 76; Hatfield and Patterson, 1983) quantify the ambiguity or regularity of a sound in terms of the number of grapheme representations associated with it and interpret phonologically plausible spelling errors as errors in which ambiguous or orthographically irregular words are spelled as they sound. But the relation goes both ways, phonologically plausible errors are also sound-to-letter errors.

These definitions affect the categorization of lexical agraphic patients' spelling errors. In the following list from the Beauvois and Dérousné corpus (printed at the end of their paper) some errors have been selected to demonstrate how their patient's spelling errors differ from S.L.'s. The phonological transcription is Beauvois' and Dérousné's own.

Target word	Phonetic transcription	Patient's response
"unir"	/ynir/	iunir
"aveau"	/avø/	aveauf
"comite"	/kɔmite/	commite
"eglise"	/egliz/	aiglise
"beret"	/beRɛ/	berret
"leur"	/lœr/	lheur

Target word	Phonetic transcription	Patient's response
"cavite"	/kavite/	caviter
"souk"	/suk/	souc
"photo"	/fɔto/	fauto
"empiler"	/ãpile/	empiller
"santal"	/sãtal/	cental
"tank"	/tãk/	tanq

These spelling errors mirror the French phoneme-to-grapheme relations, because they can be read aloud, but the point is, that they can be interpreted as hypercorrections, not as phonological errors, and that S.L. does not make this type of error. In the Beauvois and Dérousné corpus many errors appear that resemble hypercorrections. Additions of silent letters as in "beaute" beautee show a relative total of 12%, changing of one grapheme for another as in "souk" souc, 17%, or other types of error that may be understood on the basis of the French grapheme-to-phoneme rules, but not necessarily as phonemic errors. Since Beauvois and Dérousné classify spelling errors in a manner which does not permit a complete calculation, a comparison between their patient and S.L. in terms of relative error percentages is not possible.

Hatfield and Patterson (1983) state the relative error distribution for their patient as: 58% phonemic plausible spelling errors, e.g. "bruise' bruse, "dropped" droped; 10% letter misidentifications, e.g. 'p' b; 15% phoneme-grapheme errors, e.g. "bake" bak; 17% other errors, "wove" woove. Hatfield and Patterson still define phonemic errors as plausible grapheme-to-phoneme correspondences in English, but their examples of phonemic plausible errors match well the phonemic spelling errors of S.L. Beauvois' and Dérousné's patient's absolute percentage of error is 27%, while Hatfield's and Patterson's patient is 7% in regular words and 44% in irregular words – percentages of error which also match S.L.'s.

Baxter and Warrington (1987) examine their patient's spelling with one- and two-syllable words (taken from English dictionaries) in which the sound-to-letter frequencies of occurrence and number of different graphemic representations of English are controlled. Unlike the spelling behavior of S.L., the patient's misspelling of most sounds mirrored the frequencies of English.

The other descriptions of lexical agraphia, e.g., the studies of Rapcsak *et al.* (1988), Roeltgen and Heilman (1984) and Goodman-Schulman and Caramazza (1987), do not allow detailed comparisons with the present study, but the error magnitude appears to be of the same order. For example Goodman and Caramazza report an overall level of accuracy of 65% for their patient with 87% phonologically plausible errors, while Rapcsak *et* *al.* report 60% correctness on regular words, 20% on irregular words and 70% phonological spellings.

A natural explanation of the difference between the error pattern descriptions in the studies of Beauvois and Dérousné (1981), Baxter and Warrington (1987) and the present study may be that S.L. was brain-damaged at the age of 13, whereas the other two patients were 69 and 54. Thus the difference in reading and writing experience prior to the brain-injuries could be the cause of the different spelling error patterns. S.L. had only been exposed to print for six years before his accident (in Denmark education starts at the age of seven) and for some reason was unable to relearn the sound-to-letter connections of Danish after being brain-damaged. Therefore, the two older patients' spelling errors mirror the French and English sound-to-letter systems, while S.L.'s does not mirror the Danish.

The introduction to the present study claimed that the subject was a comparatively pure, isolated case of lexical agraphia. Apart from the fact that this subject and all cases of lexical agraphia spell some irregular words correctly, and that the lexical spelling route therefore must be partially intact, it has been shown, that S.L., when he misspells, is a pure phonological speller. This probably means that the partially damaged direct lexical spelling route is dissociated from the well-preserved sublexical spelling route.

In the classic neurological theory the subject S.L. is a paraphasic of the Wernicke type (1874). His spelling difficulties accordingly follow from difficulties with inner speech or spoken forms (or from difficulties with segmentation and phonological mediation, which is not the case, obviously) (Dejerine, 1914; Geschwind, 1969; Luria, 1910, 1970; Shallice, 1981; Wernicke, 1874). His productive paraphasia is slight, however, and involves only word mobilization and no receptive language disorder can be ascertained. Certain stylistic features probably reflect the word mobilization problems, but the relationship between the paraphasia and the spelling errors does not make sense, even if the classical interpretation cannot be ruled out entirely.

The reading and spelling routes must be at least partly separated because of the differences in percentages of error. Yet S.L.'s slow reading could be construed as time consuming phonological decoding. In fact during the reading sessions S.L. stated that he read so slowly because he spelled in his head. Is S.L. then a letter-by-letter reader, who simply reverses lexical agraphic spelling in his reading (Patterson and Kay, 1982; Rapcsak *et al.*, 1990; Shallice and McCarthy, 1985; Warrington and Shallice, 1980)? Apparently not, because his reading time is independent of word length, his percentage of reading errors is low in comparison with the reported cases and he does not fit in with the reading-spelling patterns of the two types of letter-by-letter readers proposed by Patterson and Kay. Of course the slow reading could also be understood as part of a general pace reduction caused by the brain damage or as a result of his paraphasia.

The correlation between S.L.'s lexical agraphia and his multifocal lesions is hardly possible to determine by inspecting the CT-scans. His behavioral and gnostic symptoms are primarily of right-sided origin, but the left hemisphere is also damaged and a focus in the vicinity of gyrus angularis cannot be ruled out. If the lesions of the right hemisphere cause the spelling patterns of this study, it is tempting to speculate on the connection between the patient's poor-visual constructive abilities and the many 'visual' features of Danish orthography, that do not appear in S.L.'s phonemic spelling errors. Ideas like this are nothing new. See for example Coltheart's (1980, 1983) discussion of the possibility of deep dyslectic reading partially or completely by means of the right hemisphere and Landis *et al.*'s (1982) evidence for right hemisphere participation in aphasic reading and writing.

NOTES

[1] Dictionaries with letter-to-sound counts of actual texts do not exist for Danish. However, because of the lowering of the Danish short vowels during the Middle Ages the letter 'e' normally represents short /ɛ/, but also less frequently long /e:/. The letter Æ also represents the short vowel /ɛ/ (and long /ɛ:/), but even casual inspection of Danish written material reveals, that the 'e'-letter occurs far more frequently than the 'æ'-letter. The claim that words with final 'd' in connection with the sound complex short vowel + /l/ + glottal stop are more numerous than words without 'd' was based on the word material in Holmboes' retrograde dictionary.

REFERENCES

Baxter, D. M. and Warrington, E. K.: 1987, 'Transcoding sound to spelling: Single or multiple sound unit correspondences?', *Cortex* **23**, 11–18.

Beauvois, M.-F. and Dérousné, J.: 1981, 'Lexical or orthographic dysgraphia', *Brain* **104**, 21–50.

Bolla-Wilson, K., Speedie, L. J. and Robinson, R. G.: 1985, 'Phonological agraphia in a left handed patient after a right hemisphere lesion', *Neurology* **35**, 1778–1781.

Castles, A. and Coltheart, M.: 1993, 'Varieties of developmental dyslexia', *Cognition* **47**, 149–180.

Coltheart, M.: 1980, 'Deep dyslexia. A right hemisphere hypothesis', in M. Coltheart, K. E. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 326–380.

Coltheart, M.: 1983, 'The right hemisphere and disorders of reading', in A. Young (ed.), *Functions of the Right Cerebral Hemisphere*, Academic Press, London, pp. 173–197.

Dejerine, J.: 1914, *Semiologie des Affectations du Système Nerveaux*, Masson et Cie., Paris.

Deloche, G. and Andreewsky, E.: 1982, 'From neuropsychological data to reading mechanisms', *International Journal of Psychology* **17**, 259–279.

Deloche, G., Andreewsky, E. and Desi, M.: 1982, 'Surface dyslexia. A case report and some theoretical implications to reading models', *Brain and Language* **15**, 12–31.

Ellis, A. W.: 1982, 'Spelling and writing (and reading and speaking)', in A. W. Ellis (ed.), *Normality and Pathology in Cognitive Functions*, Academic Press, London, pp. 113–146.

Ellis, A. W.: 1984, *Reading, Writing and Dyslexia. A Cognitive Analysis*, Lawrence Erlbaum, London.

Ellis, A. W.: 1988, 'Modelling the writing process', in G. Denes, C. Semenza and P. Bisiacchi (eds.), *Perspectives on Cognitive Neurology*, Lawrence Erlbaum, London, pp. 189–211.

Geschwind, N.: 1969, 'Problems in the anatomical understanding of the aphasias', in A. L. Benton (ed.), *Contributions to Clinical Neuropsychology*, Aldine, Chicago, pp. 107–128.

Glushko, R. J.: 1979, 'The organisation and activation of orthographic knowledge in reading aloud', *Journal of Experimental Psychology: Human Perception and Performance* **5**, 674–691.

Goodman-Schulman, R. and Caramazza, R.: 1987, 'Patterns of dysgraphia and the nonlexical spelling process', *Cortex* **23**, 143–148.

Hatfield, F. M. and Patterson, K. E.: 1983, 'Phonological spelling', *Quarterly Journal of Experimental Psychology* **35A**, 451–468.

Holmboe, H.: 1978, *Dansk Retrogradordbog*, Akademisk Forlag, Copenhagen.

Holmes, J. M.: 1978, ''Regression' and reading breakdown', in A. Caramazza and E. B. Zuriff (eds.), *Language Acquisition and Language Breakdown. Parallels and Divergencies*, John Hopkins University Press, Baltimore, pp. 87–98.

Kihl, P.: 1986, 'A Danish schoolboy's rules of spelling', *International Review of Applied Linguistics* **24**, 321–328.

Kihl, P.: 1988, *En skoledrengs staveregler. En undersøgelse af strukturen i og motiverne til 700 stavefejl i 1200 ord stavet af et 7–8 årigt københavnsk barn i løbet af 2. klasse*, Odense Universitetsforlag, Odense.

Landis, T., Graves, R. and Goodglass, H.: 1982, 'Aphasic reading and writing: Possible evidence for right hemisphere participation', *Cortex* **18**, 105–112.

Luria, A. R.: 1910, 1970, *Traumatic Aphasia*, Mouton, The Hague.

Maegaard, B. and Ruus, H.: 1981, *Hyppige ord i danske romaner*, Gyldendal, Copenhagen.

Margolin, D. I.: 1984, 'The neuropsychology of writing and spelling: Semantic, phonological, motor and perceptual processes', *Quarterly Journal of Experimental Psychology* **36A**, 459–484.

Marshall, J. C. and Newcombe, F.: 1973, 'Patterns of paralexia. A psycholinguistic approach', *Journal of Psycholinguistic Research* **2**, 175–199.

Molbæk Hansen, P.: 1983, 'An orthographic normalizing program for Danish', *Annual Report of the Institute of Phonetics, University of Copenhagen* **17**, 87–109.

Monsell, S., Patterson, K. E., Graham, A., Hughes, C. H. and Milroy, R.: 1992, 'Lexical and sublexical translation of spelling to sound: Strategic anticipation of lexical status', *Journal of Experimental Psychology: Learning, Memory, and Cognition* **18**, 452–467.

Noesgaard, A.: 1945, *Fejltyper i dansk retskrivning*, Fr. Bagge, Copenhagen.

Patterson, K. E.: 1981, 'Neuropsychological approaches to the study of reading', *British Journal of Psychology* **72**, 151–174.

Patterson, K.: 1988, 'Acquired Disorders of spelling', in G. Denes, C. Semenza and P. Bisiacchi (eds.), *Perspectives on Cognitive Neurology*, Lawrence Erlbaum, Howe, pp. 213–229.

Patterson, K. and Kay, J.: 1982, 'Letter-by-letter reading: Psychological descriptions of a neurological syndrome', *Quarterly Journal of Experimental Psychology* **34A**, 411–441.

Patterson, K. E., Marshall, J. C. and Coltheart, M. (eds.), 1985, *Surface Dyslexia. Neuropsychological and Cognitive Studies of Phonological Reading*, Lawrence Erlbaum, London.

Patterson, K. E., Seidenberg, M. and McClelland, J. L.: 1989, 'Connections and disconnections: Acquired dyslexia in a computational model of reading processes', in R. G. M. Morris (ed.), *Parallel distributed processing: Implications for Psychology and Neurobiology*, Oxford University Press, Oxford, pp. 131–181.

Rapcsak, S. Z., Arthur, S. A. and Rubens, A. B.: 1988, 'Lexical agraphia from focal lesion of the left precentral gyrus', *Neurology* **38**, 1119–1123.

Rapcsak, S. Z. and Rubens, A. B.: 1990, 'Disruption of semantic influence on writing following a left prefrontal lesion', *Brain and Language* **38**, 334–344.

Rapcsak, S. Z., Rubens, A. B. and Laguna, J. F.: 1990, 'From letters to words: Procedures for word recognition in letter-by-letter reading', *Brain and Language* **38**, 504–514.

Roeltgen, D. P.: 1985, 'Agraphia', in K. M. Heilman and E. Valenstein (eds.), *Clinical Neuropsychology*, Oxford University Press, New York, pp. 75–96.

Roeltgen, D. P. and Heilman, K. M.: 1984, 'Lexical agraphia: Further support for the two-system hypothesis of linguistic agraphia', *Brain* **107**, 811–827.

Roeltgen, D. P., Sevush, S. and Heilman, K. M.: 1983, 'Phonological agraphia: Writing by the lexical-semantic route', *Neurology* **33**, 755–765.

Rothi, L. J. G., Roeltgen, D. P. and Kooistra, C. A.: 1987, 'Isolated lexical agraphia in a right handed patient with a posterior lesion of the right cerebral hemisphere', *Brain and Language* **30**, 181–190.

Sasanuma, S.: 1980, 'Acquired dyslexia in Japanese. Clinical features and underlying mechanisms', in M. Coltheart, K. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 48–90.

Sasanuma, S.: 1984, 'Can Surface Dyslexia Occur in Japanese?', in L. Henderson (ed.), *Orthographies and Reading*, Lawrence Erlbaum, London, pp. 43–56.

Seidenberg, M. S. and McClelland, J. L.: 1989, 'A distributed, developmental model of word recognition and naming', *Psychological Review* **96**, 523–568.

Shallice, T.: 1981, 'Phonological agraphia and the lexical route in writing', *Brain* **104**, 413–429.

Shallice, T. and McCarthy, R.: 1985, 'Phonological reading: From patterns of impairment to possible procedures', in K. E. Patterson, J. C. Marshall and M. Coltheart (eds.), *Surface Dyslexia. Neuropsychological and Cognitive Studies of Phonological Reading*, Lawrence Erlbaum, London, pp. 361–397.

Shallice, T. and Warrington, E. K.: 1980, 'Single and multiple component central dyslectic syndromes', in M. Coltheart, K. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 119–145.

Thorsen, N. and Thorsen, O.: 1985, *Fonetik for sprogstuderende*, Københavns Universitet, Institut for Fonetik.

Warrington, E. K. and Shallice, T.: 1980, 'Word-form dyslexia', *Brain* **103**, 99–112.

Wernicke, C.: 1874, *Der aphasische Symptomen-Complex*, Cohn & Weigert, Breslau.

RENÉE C. KAUFMAN AND LORAINE K. OBLER

CLASSIFICATION OF NORMAL READING ERROR TYPES

ABSTRACT. In the alexia literature it is assumed that educated normals do not make reading errors. When the possibility that they do is brought to their attention, however, normal adult readers can indeed notice and identify reading errors. They find themselves retracing their steps when a word or word-string appears non-sensical. Two neurologically normal subjects collected 573 such 'slips of the eye' over the course of approximately one year. Errors were from newspapers and magazines; the subjects tore out the page with the target, circling it and writing the error. Errors were classified post-hoc into two major categories; about two-thirds were single word substitutions (e.g., "Adriatic" read as "Atlantic"), and the remainder consisted of heterogeneous errors, which were further subdivided. These data were not immediately comparable to those of brain-damaged patients because we looked at words in discourse context. However, for the single word substitution errors, with the exception of homonyms, there were no categories we found for these normals that have not been reported in brain-damaged patients. The data pattern suggests that normal adults employ an interactive approach in the task of silent reading. The variety and nature of the errors observed imply the availability and use of both top-down and bottom-up reading strategies.

INTRODUCTION

Neurolinguists observe systematic errors in adult language processing in order to deduce information about normal language processes too complex to observe when errors are not made (Caplan, 1987; Caramazza, 1986; Marshall, 1982, 1986). In the past two decades, neurolinguists have developed techniques for analyzing the reading errors of brain-damaged adults in order to demonstrate several routes to single word reading in normal adults: one via phonological decoding (Coltheart *et al.*, 1983; Marshall and Newcombe, 1973; Newcombe and Marshall, 1985), one via word recognition with comprehension (Coltheart, 1980; Marshall and Newcombe, 1973), and a third, used by demented patients, via word recognition without comprehension (Schwartz *et al.*, 1980). The tasks used are unnatural; it is rare that normal adults read word lists aloud. In this study, by contrast, we observe word errors in silent reading of texts.

In the literature on brain-damaged subjects with reading disorders it is assumed that educated normals do not make reading errors. When the possibility that they do is brought to their attention, however, they can indeed notice and identify reading errors. One finds oneself retracing one's steps when a word or word-string appears non-sensical. As with 'slips of

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the tongue' or 'false starts', one often goes back and corrects reading errors without even being aware of having done so.

The purpose of this study was to examine whether normal subjects make the same sorts of errors that brain-damaged subjects make, and consider what these errors tell us about normal reading processes. The focus of this paper is to classify the sorts of reading errors our normal subjects reported.

SUBJECTS

The subjects of this study were two normal women who were, at the time of data collection, aged 38–39 and 40–41. They are native speakers of English with no known reading deficits nor difficulty or delay in learning to read. Both subjects have studied a number of years beyond the Master's degree, and read heavily, often under time constraints, on both professional and personal topics. Both subjects had taken speed reading courses in early adulthood but felt that these courses had not changed their already fast reading style markedly or permanently.

The subjects agreed to monitor their own errors as these occurred in silent reading over the course of approximately one year's time. Only those errors which were realized during the reading of newspapers, magazines, or other throwaway materials were collected for use in this study; all of these errors were recorded. In each instance, the subject underlined or circled the target, noting in the margin the precise nature of the error made. The target with its accompanying notations was then torn from the larger text and preserved.

RESULTS

A total of 573 errors were collected. Several 'passes' were made through the data in order to classify the errors. The data were essentially separated into two major categories; the first was an easily identified grouping of single word substitutions for other single words (e.g. "expansive" for "extensive"). The second grouping was heterogeneous and was comprised of all other errors. The single word misreadings accounted for 396 of our 573 errors, or 69.1% of our data. The 'other' group accounted for 177 of our 573 errors, or 30.9% (see Table 1). Strikingly similar percentages obtained for each of the two subjects, as is evident in the table.

The two major error types were further subdivided and in large measure fell easily into a variety of categories. Because virtually all of the single-word and substitution errors are what are called 'visual' errors in the literature on brain-damaged subjects, we will call that group 'visual' errors

TABLE 1

Single word substitution ('visual') errors vs. other ('non-visual') errors (% of total errors).

Subject(s)	Visual	Non-Visual
Both readers ($n = 573$)	69.1 ($n = 396$)	30.9 ($n = 177$)
RCK ($n = 316$)	71.2 ($n = 225$)	28.8 ($n = 91$)
LKO ($n = 257$)	66.5 ($n = 171$)	33.5 ($n = 86$)

in this paper. The more heterogeneous group we will call 'non-visual' errors, although we hardly intend to claim there is no visual component in them at all.

'NON-VISUAL ERRORS'

Consider our classification of the 'non-visual' errors. We list these in their relative order of occurrence with the exception of multiply determined errors which should be second as they account for 21.5% of our non-visual errors, but are treated last for exposition purposes: (1) parsing errors, (2) word omissions, (3) word insertions, (4) homographs (same spelling; different pronunciation; different meaning), (5) word transpositions, (6) homonyms (same spelling; same part of speech; same pronunciation; different meaning), (7) misreadings of numbers, (8) exchanges, (9) punctuation and diacritical marks, and (10) multiply determined errors.

The most frequently occurring 'non-visual' errors were parsing errors (35.0%). These parsing errors took two forms; single word misreadings such as "posts" read as a noun when in fact it was used as a verb, and instances where one reader had to read a phrase or sentence several times before the sense materialized. For example, one reader reported having to read the phrase "all that man has learned" three times before appreciating the meaning. When we analyzed the types of misreadings involved in these misparsings, no pattern emerged. A surprisingly large number of English words can play more than one syntactic role, and all possible wrong readings seem to have occurred (e.g. noun as adjective, noun as verb, adverb as adjective, etc.).

TABLE 2

Percentages of other ('non-visual') errors.

Error type	Both readers	RCK	LKO
Parsing	35.0	39.6	30.2
Multiply determined	21.5	20.9	22.1
Omissions	13.5	17.6	9.3
Insertions	9.6	8.8	10.4
Homographs	6.2	3.3	9.3
Transpositions	3.9	3.3	4.6
Homonyms	2.8	2.2	3.5
Numbers	2.8	0.0	5.8
Exchanges	2.2	2.2	2.3
Diacritical and Punctuation	2.2	2.2	2.3

Overall the next most frequent of the non-visual errors were those of word omission; this group accounted for 13.5% of the non-visual errors. Omissions also took two forms; that is, there were single word omissions such as "if you're not looking forward to paying your taxes" read "if you're looking forward to paying your taxes", and there were multiword and phrase omissions such as "people really want to win and they want it badly" read as "people want to win badly".

Word insertions were the next most frequent category of non-visual error overall at 9.6%. Insertions could be single-word insertions or phrase insertions; for example reading the headline "A Woman Is Killed By An L.I.R.R. Diesel" as "A Woman Is To Be Killed By An L.I.R.R. Diesel".

The next most frequent error type we call homograph misreadings (6.2%). These were different from parsing errors in that spelling did not change but pronunciation changed and part of speech may or may not have changed. For example, where the text said "pointing out the tears where the knife had entered", our reader read /tɪrz/ for /tɛrz/. Two interesting errors made by one reader appeared to be homograph misreadings due to reading an English word as if it were a word in a foreign language known to her. Our reader read "!A Los Angeles Auction!" and interpreting Los Angeles as a Spanish phrase, asked herself why anyone would hold an auction to the angels. Note that this was a headline with an exclamation point at the beginning and the end of the line. In Spanish, of course, the first exclamation point would have been inverted; in English, an initial exclamation point is not used. Thus there was a partial cue to the reader to interpret the phrase in Spanish. In the other example, the phrase was "... the older man all pink pate and owlish stare ... ". Our reader read /pet/ as /pæte/, a word which we believe can be written with or without the accent marks in English. In this instance, then, it is particularly surprising that our reader chose the more French reading despite the strictly English context.

Transpositions involved the simple movement of a word from one location in the sentence to another, as in "in one of which the ... " was read as "in which one of the ... ". For us transpositions made up 3.9% of all non-visual errors. Some of these involved moving a word up from the line below.

The more minor categories should be discussed briefly. The first we termed homonym errors. This category included errors such as reading the word "rock" in the headline "A Book of Rock Art" and interpreting it to mean a stone, when in fact the context revealed that it meant a form of music.

As to the few number misreadings, one reader caught herself misreading numbers on several occasions. These errors were primarily number reversals as in "1892" for "1982" but also included number substitutions such as "13" for "33" or number omissions such as "7" for "47". In fact, these errors accounted for 5.8% of all her 'non-visual' substitutions.

Exchange errors, relatively rare at 2.2% of all errors, were those in which two words simply traded positions within the sentence; an example of this type of error was the headline "More Let's Articulate" read as the phrase "Let's More Articulate". In most instances where these exchanges occurred, words appeared one above the other on consecutive lines on a page.

Equally unusual were errors associated with misreading of diacritical marks or punctuation marks. In the sentence "Virtually all living cells are proteins: hormones, enzymes, antibodies, hair, skin, bones and so on", the colon sets off a list of nouns which are types of proteins. The reader first read the colon as a comma and in so doing identified proteins in parallel with rather than inclusive of the list of nouns which followed.

For each of the two readers there were a few reading errors that did not fit exclusively into any particular category either because it was apparent that a number of processes contributed to the error or because precisely what was going on was unclear. Consider the headline, "Chilly Zones in the Comfort World". Our reader read this as "Comfort Zones in a Chilly World", not only transposing the words "chilly" and comfort" but also misreading the word "a" for the word "the". In the example "some 1,400" read as "sometimes", "1,400" was omitted; "times" was either a substitution or an insertion unrelated to the omission.

Each of the two readers on at least one occasion inserted one word while deleting two, inserted two words while deleting one, or inserted two words while deleting two. These multiply determined errors constituted 21.5% of all 'non-visual' errors. We found no pattern in the combination of error types.

VISUAL ERRORS

Single word substitution accounted for more than two thirds of our errors (69.1%). We identified four different types of error. The first three of them may be considered semantically related: derivational errors, inflectional errors, and other semantic errors (non-inflectional and non-derivational). The fourth category is visually related words that are not semantically related.

As we treat in more detail elsewhere (Kaufman and Obler, in preparation) we asked three raters to rate the extent to which the targets and errors of each of the pairs were semantically related. Each pair of words was evaluated on a 5-point scale from 0 (highly unrelated) to 4 (highly related). The results could be easily divided into two sets; we may call them 'quite semantically related' and 'semantically minimally related'. From the larger category of pairs determined by the raters to be semantically related, we then extracted inflectional errors and derivational errors. The remaining semantic errors were then called 'exclusively semantic' errors. It should be noted here that there was high interrater reliability for our three raters.

We often noted that items that our raters judged to be semantically related also shared visual characteristics such as word length, letters in common, or position of specific letters in the word. For example, "doctors" and "donors" were judged to be semantically related. They have the first two and the last three letters in common (over 50% of all letters and in similar relative positions); "Armenians" and "Americans" share eight out of nine letters (88%) with these letters in similar relative positions and the two words are of identical lengths.

In order to explore orthographic features that might influence single-word reading errors, we included all single-word substitutions. We did this because it was impossible to exclude visual similarities from practically all of the single-word substitution errors, and because single-word substitution errors that everyone would agree are visual errors constituted the great majority of our errors. We combined all single word substitutions in order to look at a number of orthographic factors that might have influenced reading errors. These included word length, letter constituency and letter position of target versus error. In addition we examined part of speech and frequency of occurrence of each word in the English language. We then looked for any interaction between these various elements.

In-depth investigation of these visual errors is the subject of a paper in preparation. Our preliminary observations can be summarized as follows. Specific letters are no more or less likely to engender errors than others. Target and error words began with the same letter in approximately three quarters of all instances, ended with the same letter in approximately three quarters of all instances, and both began and ended with the same letter in approximately half of all instances. The mean word length of error words was essentially the same as the mean word length of target words; also our readers tend to err on words that are on average slightly longer than those of the genre from which they come.

CONCLUSION

The fact that such a high percentage of the errors our readers caught are errors in reading single words confirms the ecological validity of others' research on brain-damaged subjects looking only at single-word list reading. Clearly a component of silent prose reading involves identifying and 'reading' single words. However, our method of data collection did permit error types that have not, to our knowledge, been reported for brain-damaged subjects, namely, homonym misreadings, transpositions, adding words, and omitting words. Such errors, combined with the high percentage of 'visual' errors, provide confirming evidence to those theories of reading that assume a substantial top-down component. Clearly neither are all letters identified before the reader assumes a given word to have been read, nor is each and every word read in the correct order before the reader assumes a phrase has been read.

This top-down processing (Goodman, 1970; Smith and Holmes, 1971; Smith, 1971), as shown by our data, would seem to interact with estimates of part-of-speech, word length, word frequency, and recognition of letters on the periphery of the word, to determine in more than one way a reader's assuming a single reading for a word or groups of words.

Only in the rare event that the resulting meaning is incongruous is one alerted to reread the prior text and even this is usually carried out without awareness unless one is enlisted in a project like the one reported on here. Of course, as with speech error collection, we cannot try to estimate how many reading errors did not yield enough incongruity to be noticed by our subjects.

One final comment should be made on a type of errors seen in some brain-damaged patients, and in children learning to read but not seen in our sizeable corpus, namely, phonological decoding errors. It would appear that in the hasty reading that appears to have engendered most of our readers' errors, it is whole word recognition processes that are the goal, and either, as we suspect, no or virtually no phonological decoding gets done in the silent reading of the healthy adult, or none of it is erred on. Some might consider the homonym misreading errors 'phonological' errors in that one phonological representation is substituted for another; we see them as different categories however, and thus are able to note the exclusion from our data of phonologically 'correct' decodings of irregular words that would have resulted in non-words.

Of course bottom-up reading processes (Gough, 1972; LaBerge and Samuels, 1974) are evident from our data too, in that most errors are 'visually' motivated, that is, include some or all of the actual letters read. Interactive approaches (Stanovich, 1980) incorporating top-down processes (including syntactic and semantic procedures) and bottom-up processes (including letter and word-boundary identification) seem to be employed concurrently.

REFERENCES

Caplan, D.: 1987, *Neurolinguistics and Linguistic Aphasiology*, Cambridge University Press, Cambridge.

Caramazza, A.: 1986, 'On drawing inferences about the structure of normal cognitive systems from the analysis of patterns of impaired performance: The case for single patient studies', *Brain and Cognition* **5**, 41–66.

Coltheart, M.: 1980, 'Deep dyslexia: A review of the syndrome', in M. Coltheart, K. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 22–47.

Coltheart, M., Masterson, J., Byng, S., Prior, M. and Riddoch, J.: 1983, 'Surface dyslexia', *Quarterly Journal of Experimental Psychology* **35A**, 469–495.

Goodman, K. S.: 1970, 'Reading: A psycholinguistic guessing game', in H. Singer and R. B. Ruddell (eds.), *Theoretical Models and Processes of Reading*, International Reading Association, Newark DE, pp. 497–508.

Gough, P. B.: 1972, 'One second of reading', in J. F. Kavanagh and I. G. Mattingly (eds.), *Language by Ear and by Eye*, MIT Press, Cambridge MA, pp. 331–358.

LaBerge, D. and Samuels, S. J.: 1974, 'Toward a theory of automatic information processing in reading', *Cognitive Psychology* **6**, 293–324.

Marshall, J. C.: 1982, 'What is a symptom complex?', in A. Arbib, D. Caplan and J. C. Marshall (eds.), *Neural Models of Language Processes*, Academic Press, New York, pp. 389–409.

Marshall, J. C.: 1986, 'The description and interpretation of aphasic language disorders', *Neuropsychologia* **24**, 5–24.

Marshall, J. C. and Newcombe, F.: 1973, 'Patterns of paralexia: A psycholinguistic approach', *Journal of Psycholinguistic Research* **2**, 175–199.

Newcombe, F. and Marshall, J. C.: 1985, 'Reading and writing by letter sounds', in K. E. Patterson, J. C. Marshall and M. Coltheart (eds.), *Surface Dyslexia*, Lawrence Erlbaum, London, pp. 35–51.

Schwartz, M. F., Saffran, E. M. and Marin, O. S. M.: 1980, 'Fractionating the reading process in dementia: Evidence for word-specific print-to-sound associations', in M. Coltheart, K. Patterson and J. C. Marshall (eds.), *Deep Dyslexia*, Routledge & Kegan Paul, London, pp. 259–269.

Smith, F.: 1971, *Understanding Reading*, Holt, Rinehart & Winston, New York.

Smith, F. and Holmes, D. L.: 1971, 'The independence of letter, word, and meaning identification in reading', *Reading Research Quarterly* **6**, 394–415.

Stanovich, K. E.: 1980, 'Toward an interactive-compensatory model of individual differences in the development of reading fluency', *Reading Research Quarterly* **16**, 32–71.

ANTÓNIO MARTINS DA SILVA AND BELINA NUNES

LANDAU–KLEFFNER SYNDROME: A NEURONAL MATURATION DEFICIT?

ABSTRACT. The Landau–Kleffner syndrome (LKS) is a well-defined childhood disorder in spite of some variants. An acquired aphasia, multifocal spikes and spike and wave discharges, epileptic seizures and behavioral disturbances characterize the syndrome.

We studied a ten-year old boy with LKS starting at five years old with myoclonic seizures (eye blinking and falls) and a progressive and almost total aphasia. There was no seizure response to valproate therapy. An electroclinical myoclonic status was reverted by clonazepam, which was maintained in low doses with complete suppression of seizures even after clonazepam withdrawal. There has been slight language improvement during follow-up.

The influence of epilepsy on cognition including language tasks may also involve permanent deficits on reference skills due to an interference on local maturation of neural aggregates and may be suggested as a cause of Landau–Kleffner syndrome.

INTRODUCTION

The Landau–Kleffner syndrome (LKS) is a childhood disorder characterized by the association of an acquired aphasia and paroxysmal electroencephalographic abnormalities.

Aphasia is the first symptom in about 45% of patients with the characteristics of an auditory verbal agnosia. The child progressively becomes unresponsive to familiar noises, loosing spontaneous verbal speech; in about 18% of the patients there is a stepwise installation of the aphasia (Beaumanoir, 1985).

The EEG is always abnormal, but non-specific and variable within and between patients. Paroxysmal activity is most often located in parieto-occipital or temporal areas and is frequently activated by sleep. Cole *et al.* (1988), in a review of 95 cases, found that discharges were either bitemporal, generalized or multifocal in 88% of patients and in only 12% were discharges strictly unilateral.

Epileptic seizures and behavioral or psychomotor disturbances are also usually present. Seizures occur in about 70% of patients and are most frequently generalized or motor partial seizures (Beaumanoir, 1985). The relationship between aphasia and hyperkinesia or other behavioral disturbances is not yet well established.

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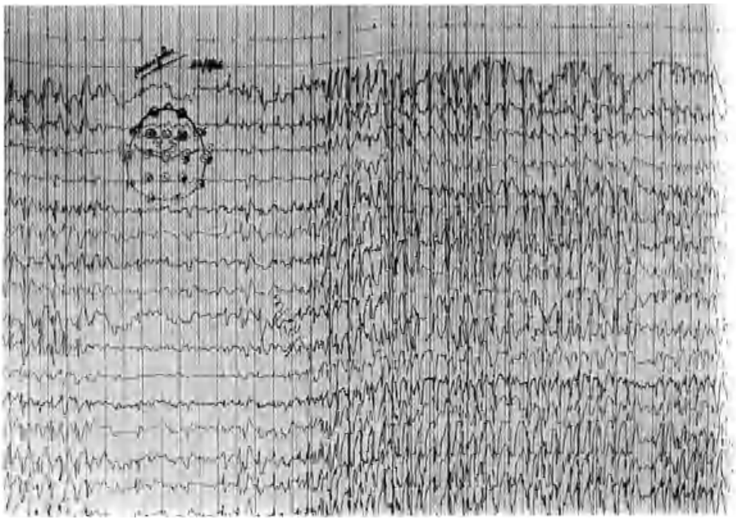

Fig. 1. EEG recording showing continuous generalized spike and wave and polyspike and wave bursts. Date: 22/08/86. TC: 0.3 sec., paper speed 30 mm/sec., gain: 7 μV/mm.

We present a case report of a child with LKS followed up for five years, with progressive aphasia and behavior problems progressing over a few months, associated with frequent myoclonic seizures.

CASE REPORT

This right-handed boy was born in 1981 after a normal gestation and delivery. He had a normal psychomotor development including language acquisition. In August 1985, when he was 4 years and 4 months he started having frightful nightmares, sometimes after TV movies and hyperkinetic behavior during the day. A few weeks later his mother remarked frequent staring with eye-blinking. His language became progressively less fluent, monosyllabic, with difficulties in naming common objects. He could still recognize familiar noises such as doorbell and the telephone, but soon he was also unresponsive to sounds. Frequent myoclonic seizures with eye-blinking and falls were observed by his pediatrician who ordered an EEG and the child was started on valproate therapy, 200 mg per day. There was a continuous loss of language and in December 1985 he was almost mute.

In July 1986, his mother discontinued the treatment because she related the frequent falls to valproate therapy. One month later, the patient was

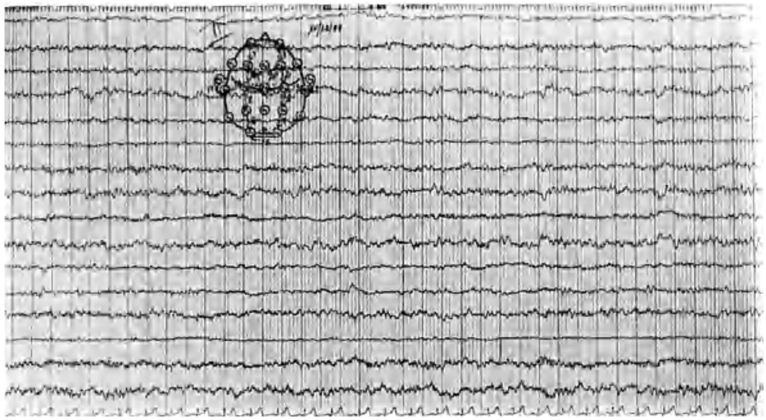

Fig. 2. An almost normal EEG recording, four months later. Date: 15/12/86. TC: 0.3 sec., paper speed 30 mm/sec., gain: 7 μV/mm.

Fig. 3. EEG at age 10, with bitemporal spike and wave bursts. Date: 17/07/91. TC: 0.3 sec., paper speed 30 mm/sec., gain: 7 μV/mm.

referred to our hospital and after consultation an EEG was performed showing continuous generalized spike and wave and polyspike and wave discharges associated with myoclonic seizures (body and hand myoclonic jerks). This electroclinical myoclonic status was reverted with intravenous administration of 1 mg clonazepam, remaining only localized left fronto-temporal spike and wave bursts. The boy was started on oral clonazepam, 2 mg per day with total seizure control: the patient remained seizure-free

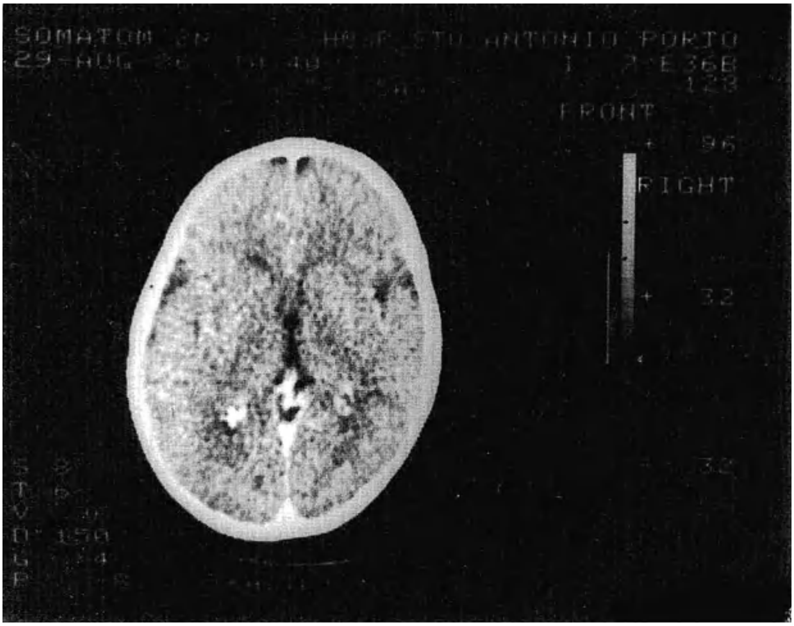

Fig. 4. CT scan at age 5 (date: 29/08/86).

after clonazepam withdrawal in December 1989. EEG recordings during follow-up still show rare and short-duration, left temporoparietal spike and wave bursts with increased duration and bilateralization during sleep. Figures 1, 2 and 3 illustrate the EEG evolution.

Brainstem auditory evoked potentials recorded at two different occasions were normal. CT scans, at ages 5 and 10, and a recent MRI all showed a questionable atrophy of both temporal lobes (Figures 4, 5 and 6).

About six months after seizure control he was able to say a few words. He is on a program of speech therapy but his spontaneous verbal speech is still scarce, telegraphic. He has decreased comprehension of spoken language and delay in response and sentence formulation with paraphasias when reading aloud. He is able to copy correctly small words and to perform simple arithmetics. There has also been an improvement of his hyperkinetic behavior.

Nowadays at 13 years old the boy is still aphasic with strong speech reduction.

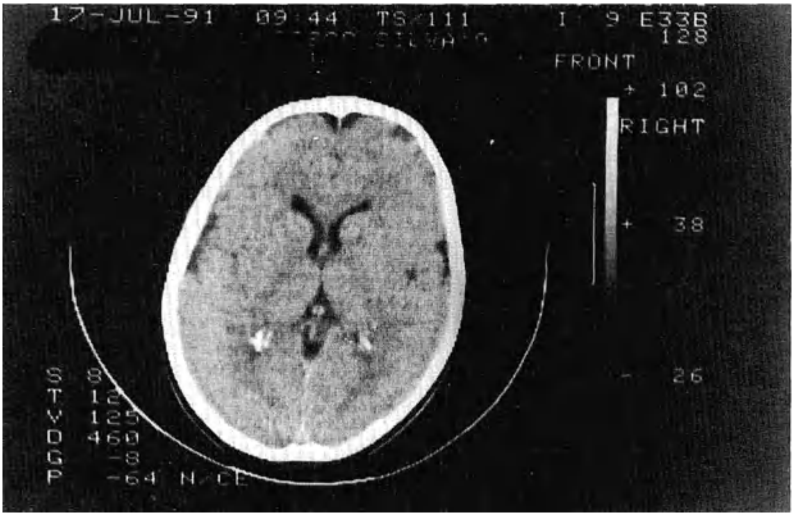

Fig. 5. CT scan at age 10 (date: 17/07/91).

DISCUSSION

This case illustrates the usual manifestations of LKS, with progressive aphasia, EEG paroxysmal activity, seizures and behavioral disturbances. However, at the beginning, epilepsy was difficult to control with frequent myoclonic seizures not responding to valproate.

Electroclinical myoclonic status was reverted by intravenous clonazepam. EEG abnormalities were attenuated and seizures completely abolished by oral clonazepam therapy but without such a prompt language recovery as in the case reported by Ravnik (1985).

A structural lesion in LKS has been searched by several authors but so far with controversial results. Malformative, neoplastic and vascular lesions were never proved. Recently, Otero *et al.* (1989) reported a case of a child with a cysticercus in the left temporal lobe as the presumed cause of LKS. In our patient a structural lesion does not seem plausible, as far as CT and MRI investigations, because the slight enlargement of the subarachnoid space remains stable during the follow-up period and there are no associated parenchymatous lesions.

This syndrome has been considered a functional disorder due to a rupture in the loop: hearing – verbal integration – spoken language (Beaumanoir, 1985). Kellerman (1978) locates this interruption at the level of subcortical connections responsible for the activation of the temporal

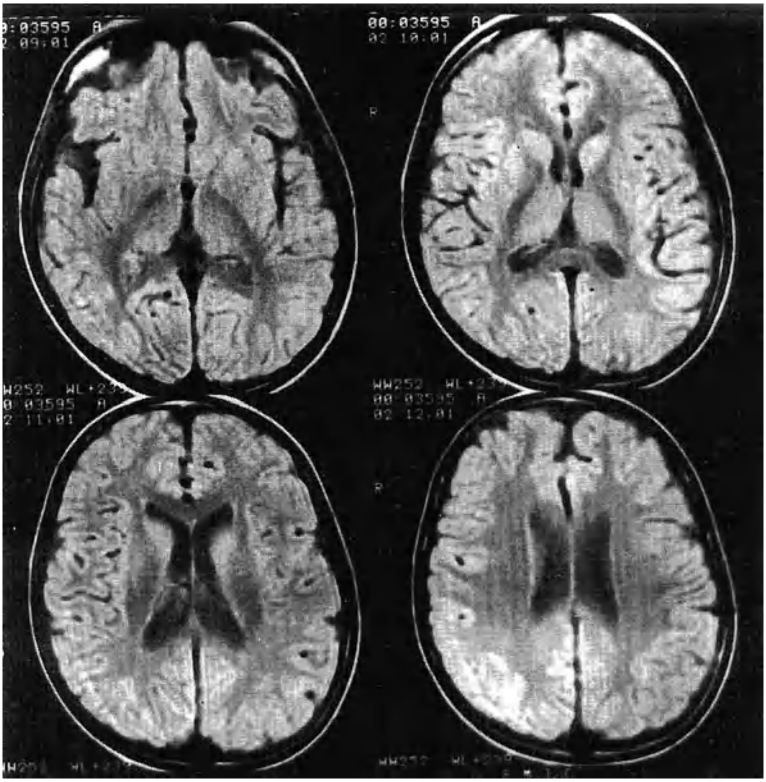

Fig. 6. A proton density MRI, at age 10 (date: 27/08/91). Questionable enlargement of the subarachnoid space at both temporal lobes.

regions. Other possible mechanism could be a delayed or halted maturation of the functional structures and of the interhemispheric pathways (Njiokitgien, 1983).

The classification of this syndrome among the epilepsies also raises some questions. According to Aicardi (1988), epileptic syndromes are characterized not only by the type or types of seizure that occur, but also by other neurological manifestations such as interictal EEG abnormalities and occasionally by other non-neurological disturbances. In this disorder, about 30% of the patients have no seizures (Beaumanoir, 1985) and so the inclusion of these cases as epileptic syndrome implies the acceptance of an electrophysiological definition of epilepsy (Binnie, 1990).

Our hypothesis is that language impairment in Landau–Kleffner syndrome could be caused by the frequent subclinical paroxysmal abnormalities at a critical time period of language development, usually between 3 and 5 years. The influence of epileptiform discharges on cognitive functions is well known with disruption of performance during EEG discharges without overt seizures. This disturbance, named by Binnie (1980) transitory cognitive impairment (TCI) has been found during memory tests, lecture and reading tasks as well as in motor performance tasks (Binnie *et al.*, 1987).

Recently we reported a study of 55 patients with subclinical EEG discharges. We found TCI in 21 out of the 32 patients with frequent discharges during performance of computerized verbal and visuo-spatial memory tasks. Moreover, it seems to be a task specific stimulation of some cortical areas, with changing of type and location of the epileptiform events during test performance (Martins da Silva *et al.*, 1992).

On LKS we can postulate a negative influence of epileptiform discharges on the verbal encoding, occurring in different ways and illustrating the modifications of the neuronal connections. There is probably an interference with the acquisition of verbal knowledge at different levels and at different times. On the other hand, the increased frequency of such epileptiform events may determine failures on the verbal performance testing. According to the relationship between normal system equilibrium and correct responses, Freeman (1991) suggested that the neuronal systems recognize events when a synchronization of neuronal activity occurs, breaking down any chaotic neuronal work.

The stimulation of specific cortical areas during mental processing could synchronize the neuronal activity and disrupt an unstable mechanism of excitation/inhibition reaching a critical threshold in epileptiform events generation. Otherwise, the synchronization of some neuronal networks disturbed by the presence of new and abnormal potentials (epileptiform discharges) may induce disturbances of mental processing.

The neuropsychological and electrophysiological approaches of the Landau–Kleffner syndrome must be integrated, with continuous test performance during EEG monitoring, in order to detect cognitive impairment related to subclinical epileptiform EEG discharges.

Recently, Paquier *et al.* (1992) described six children with this syndrome and stressed the importance of EEG records performed during sleep due to the occurrence of electrical status epilepticus during slow sleep (ESES) in these patients. They hypothesize that ESES may be responsible for the functional disorganisation of the cortical areas that play a role in language functions.

To conclude, we would like to emphasize the role of subclinical epileptiform EEG discharges either during vigilance or sleep as a plausible factor of language disruption in this syndrome, because of their interference on maturation of the neuronal circuitry of language functional areas.

REFERENCES

Aicardi, J.: 1988, 'Epileptic syndromes in childhood', *Epilepsia* **29** (Suppl. 3), S1–S5.

Beaumanoir, A.: 1985, 'The Landau–Kleffner syndrome', in J. Roger, C. Dravet, M. Bureau, F. E. Dreifuss and P. Wolf (eds.), *Epileptic Syndromes in Infancy, Childhood and Adolescence*, John Libbey Eurotext, London, pp. 181–191.

Binnie, C. D.: 1980, 'Detection of transitory cognitive impairment during epileptiform EEG discharges: Problems in clinical practice', in B. M. Kulig, H. Meinardi and G. Stores (eds.), *Epilepsy and Behavior*, Swets & Zeitlinger, Lisse, pp. 91–97.

Binnie, C. D.: 1990, 'Generalized epilepsy: Ictal and inter-ictal', in J. A. Wade & R. J. Ellington (eds.), *Clinical Neurophysiology of Epilepsy: EEG Handbook*, revised edition, Vol. IV, Elsevier, Amsterdam, pp. 263–289.

Binnie, C. D., Kasteleijn-Nolst Trenité, D. G. A., Smith, A. M. and Wilkins, A. J.: 1987, 'Interactions of epileptiform discharges with cognition', *Epilepsy Research* **1**, 239–245.

Cole, A. J., Andermann, F., Taylor, L., Olivier, A., Rasmussen, T., Robitaille, Y. and Spire, J. P.: 1988, 'The Landau–Kleffner syndrome of acquired epileptic aphasia: Unusual clinical outcome, surgical experience, and absence of encephalitis', *Neurology* **38**, 31–38.

Freeman, W. J.: 1991, 'The physiology of perception', *Scientific American* **264**(2), 34–41.

Kellerman, W. J.: 1978, 'Recurrent aphasia with subclinical bioelectric status epileptic during sleep', *European Journal of Pediatrics* **128**, 207–212.

Martins da Silva, A., Nunes, B. and Cunha, J. P.: 1992, 'Epilepsy and cognition: Evidence for mutual relationship', *Bolet. Epileps.* **1**, 37–42.

Njiokitgien, Ch.: 1983, 'Callosal dysfunction, as a possible pathogenic factor in developmental dysphasia', *Neuropediatrics* **14**, 123.

Otero, E., Cordova, S., Diaz, F., Garcia-Teruel, I. and Del Brutto, O. H.: 1989, 'Acquired epileptic aphasia (the Landau–Kleffner syndrome) due to nerocysticercosis', *Epilepsia* **30**, 569–572.

Paquier, P. F., Van Dongen, H. R. and Looner, C. B.: 1992, 'The Landau–Kleffner syndrome or "acquired aphasia with convulsive disorder". Long-term follow-up of six children and a review of the recent literature', *Archives of Neurology* **49**, 354–359.

Ravnik, I.: 1985, 'A case of the Landau–Kleffner syndrome: Effect of intravenous diazepam', in J. Roger, M. Bureau, F. E. Dreyfuss and P. Wolf (eds.), *Epileptic Syndromes in Infancy, Childhood and Adolescence*, John Libbey Eurotext, London, pp. 192–193.

PART 3

COMPUTATIONAL AND LINGUISTIC APPROACHES

CHE KAN LEONG AND R. MALATESHA JOSHI

EDITORS' COMMENTS

In much of the experimental and clinical neuropsychological literature on developmental and acquired dyslexia, there is considerable emphasis on the cognitive mechanisms and the computational structure of language processing. Many of these studies deal with single word processing to delineate the general architecture of the lexical system, the representation of the lexical processing components and the nature of their interaction. In this regard, there is a shift of research paradigm or model over the years. The term model, as explained by Kuhn (1970, p. 175), refers to "... the entire constellation of beliefs, values, techniques, and so on shared by members of a given community ... It denotes one sort of element in that constellation, the concrete puzzle-solutions which ... can replace explicit rules as a basis for the solution of the remaining puzzles of normal science." Moreover, a paradigm or model "need not, and in fact never does, explain all the facts with which it can be confronted" (Kuhn, 1970, p. 18).

This rise in theoretical alternatives in the Kuhnian sense to explain empirical findings of knowledge of words may be broadly referred to (and at the risk of over-simplifying) as those of lexical access to stored lexical codes compared with spreading activation of different kinds of information. The chapters by Quinlan, and Brown and Loosemore are in this direction. They discuss in some detail the nature of the mental representation of the lexical system and argue for parallel distributed processing to explain dyslexic reading and spelling. To their detailed works, we will add just a few general comments.

In his early work on reading, Rumelhart (1977) discussed the interactive approach using visual, orthographic, phonologic, semantic, syntactic and pragmatic information. Adams (1979) found that in identifying real words, the component letter units are activated by pairwise letter unit associations proportional to their frequencies and these associations are much weaker for non-words. Her results suggest that frequency of occurrence of pairs of letter units and orthographic redundancy or sequential predictability affect the associative strength in the visual processing of lexical items. The partial model of reading of McClelland and Rumelhart (1981) represents three levels of processing: visual features of letters, letters and words. There are both positive and negative connections from visual features to the letters and words within the linguistic constraints of English. Many parallel orthographic and phonological units can be simultaneously activat-

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ed, and these units are constrained from both above (top-down) and below (bottom-up) and may decay with time. The interactive activation computer program of McClelland and Rumelhart (1988) provides a detailed account of processing during letter identification. A succinct 'formal sketch' of the computational framework of the 'architecture of mind' of connectionist models is given by Rumelhart (1989).

These connectionist models are seen as providing an important framework for simulating modelling to forge stronger links of theories to data to delineate knowledge representations [of orthography and phonology] (Seidenberg, 1993a). In another recent explication of his research program, Seidenberg (1992) answers some of the criticisms of linguistic inadequacy of connectionism. Linguists have usually sought from psychological experiments verification of *learnability* and *parsability* of a grammar as a theory of knowledge of language. The ease and regularity with which humans learn the set of possible grammars of a language is one criterion of learnability (Chomsky, 1955/1975); and the algorithm with which the grammar is associated as one that humans actually carry out is the constraint of parsability (Culicover, 1985).

On the 'great divide' of learnability between linguistics and connectionism, Seidenberg (1992) suggests that parallel distributed processing should be seen as a novel way of representing knowledge from the initial state of the system, through the input to the system to the capacity of the system to learn. He argues forcefully that modelling such tasks as the pronunciation of words and the generation of past tenses in inflectional morphology may be explained by a single underlying mechanism. This single-route connectionist approach takes into account not only the properties of words such as frequency, length, 'regularity' or 'irregularity', as discussed in the traditional dual route model, but also the relations among words.

This spreading activation of effects of consistency or inconsistency on spelling to sound correspondences, as exhibited by learners, is also simulated in a series of studies by Seidenberg and his colleagues. Directly on the modal pattern of impairment of single word reading, especially of pseudowords and exception words, Seidenberg (1993b) suggests insufficient computational resources made available to the network during learning as another cause of dyslexia. His suggestive evidence is from simulation studies with fewer hidden units and the degradation of orthographic input, which show the modal impairment of pseudoword and exception word reading but relative preservation of regular words (see also Seidenberg and McClelland, 1989). Apparently, the reduction of hidden units makes it more difficult to encode word-specific information important for exception words, even though generalizations about regular words may still be maintained. While cautious in his interpretation and in pointing out the multiple causes of dyslexia, Seidenberg (1992, 1993a, 1993b; Seidenberg and McClelland, 1989) suggests that explicit computational models from connectionism afford us deeper insight in both research and clinical work.

The above summary discussion provides some background for the two chapters in explicating connectionism. **Quinlan** traces the traditional treatment of the orthographic, morphological and phonological nature of the abstract lexical representation of word structure; and suggests as important the notion of the 'lexical pointer' as specifying the addresses of the morpho-phonological form for the lexical entry. He further discusses the pros and cons of the traditional functional roles of lexical entries and the distributed representations of connectionist models at the levels of implementation and computation.

In their detailed chapter, **Brown and Loosemore** discuss the learnability nature of these network models and their application to the pronunciation of regular and exception words and non-words. Their simulation results show greatly increased error scores for non-words, analogous to experimental studies of dyslexia. In applying their connectionist approach to spelling of regular words (those with many 'friendly' orthographic neighbors) and irregular words (those with few friendly orthographic neighbors or 'enemies'), Brown and Loosemore simulate 'normal', 'mildy dyslexic' and 'severely dyslexic' models by providing progressively fewer hidden units. Their simulation results show higher error scores for the irregular items; and their dyslexic patterns of the model are less proficient in both accuracy and efficiency as compared with the normal version. Brown and Loosemore amply demonstrate the learnability of connectionist models in reading and spelling regular and irregular words analogous to the learning of these same words by children. Their results lend further support to the Seidenberg view of inadequate computational resources during learning as another possible explanation for dyslexic reading and spelling.

It is thus a daunting task to make even passing comments on the connectionist approach to dyslexic reading and spelling. Several remarks may be in order. One is the issue of falsifiability of the model because of the number of parameters that can be manipulated in simulation data (see Chase and Tallal, 1990). The other is the broader treatment of symbolic models in relation to parallel distributed memory and linguistic processes (see Smolensky, 1988, and open-peer commentaries). There is also some suggestion that parallel distributed processing systems that communicate among hierarchically organized layers may not be entirely incompatible with 'vertical', autonomous processing modules (Tanenhaus *et al.*, 1987). Directly on the cognitive theories of spelling (and to some extent reading) and instruction, Seymour (1992) acknowledges the efficacy of the training procedure of connectionist models, as discussed by Brown and Loosemore and others, and further suggests as useful for instruction the incorporation of explicit orthographic and morphemic structures.

The processing of English morphological structure by poor readers is the topic of discussion of the chapter by **Leong and Parkinson**. These authors emphasize the hierarchical and relational aspects of words according to word formation rules and the importance of productivity. In three main experiments using the semantic priming procedure together with a lead-in repetition priming experiment, all using reaction time measures, Leong and Parkinson explore the efficiency in processing derivational morphology in ten- to twelve-year old poor readers. There is some evidence from the rapid and accurate vocalization of complex derived forms from target base words, or base forms from target derived words, all embedded in short sentence frames, that the depth of derivational morphology plays a role in the reading performance of these children. Experimental evidence is also accumulating to show that morphological structure plays an important part in lexical representation in neurologically intact persons and aphasic patients (Caramazza, 1991).

In this regard, research studies from the morphologically 'rich' European languages support morphological constraints on word recognition, perhaps more so than in English. **Jarvella** summarizes his research studies with Italian, Dutch and Swedish subjects to explain skilled readers' use of morphologically-defined letter clusters. Without going into the debate of morphological parsing models of Full Listing, Addressed Morphology, or morphological decomposition such as the Basic Orthographic Syllabic Structure (BOSS), Jarvella shows from his results that there are differences in the clusters or forms stored (stems for Italian, morphemes for Dutch), in lexical look-up and affixation processes.

We would like to suggest that other morphologically rich languages such as Turkish, where stem formation by affixation to previously derived stem is productive, will provide another perspective on the recognition of roots in relation to the recognition of affixation, especially suffixes. Productive roots also have a special status in Hebrew where infixation of vowel patterns between the consonants of the root morpheme brings about changes in orthographic and phonological structure. The nature of alphabetic, morphemic and syllabary orthographies and their effects on reading and writing disorders are the topic of an earlier NATO Advanced Study Institute (Aaron and Joshi, 1989). There is currently considerable interest in the interactive nature of orthography, phonology, morphology and meaning in different orthographies in relation to lexical representation (Frost and Katz, 1992).

This brings us to the detailed chapter by **Luelsdorff and Chesnokov**. They explicate their linguistic notions of relations of likeness (similarity judgment) in terms of the adjacency of the more precise binders or 'precisors'. The binding conditions determine not only the possible relations between traces and their antecedents but also the distribution and movement of the adjacent letter clusters (subjacency). This approach is analogous to the operation of grammatical principles in relating names, pronouns, anaphoras to possible antecedents as articulated in the 'X-bar' and the Government and Binding (GB) theory of Chomsky (1981). Grossly simplifying, GB specifies the relevant structural relations in terms of alpha being bound by beta if alpha and beta are coindexed, beta c-commands alpha, and beta is in argument position.

Much of the Luelsdorff and Chesnokov argument is predicated on the theory of orthographic complexity to explain first and second language reading and spelling (Luelsdorff, 1991). In that volume and elsewhere, Luelsdorff discusses the degree of complexity as a function of the kind and amount of linguistic information required in relating phonemics and graphemics in a hierarchical order. Such information ranges from one-to-one, one-to-many, to many-to-one phoneme-grapheme correspondences. The context of these many-sided correspondences is sensitive to phonology, morphology, semantics, and lexis, or some kind of 'semiotic schematic' (Luelsdorff, 1991, pp. 182, 238). Within this framework of orthographic complexity and determinacy analysis, Luelsdorff and Chesnokov examine in a sample of German adults the similarity judgment based on computationally explicit analyses of pairs of English and German words, graphemes, and consonant and vowel sounds. They suggest that their computational approach to the judgment of similarities may provide greater insight into individual linguistic differences and is preferred over the more vertical approach.

As with the earlier parts in this volume, there is much in this Part 3 that should lead to further experimentation from cognitive neuropsychology, applied and computational linguistics. The discussion of connectionism and symbolism could also be seen in a broader perspective of the 'society of mind' concept (Minsky, 1987). Minsky conceptualizes mental functions as organized in a loose network of societies in which members from one society communicate with those members from another society through higher level coordinating units. There is yet another analogy from the pedagogical perspective. Boden (1989) provides a lucid account of effective classroom learning in terms of 'parallel processing' where children discuss 'localized computations' 'distributed' across the whole language and cognitive systems. The notion here accords with that of the activation of distributed representations of multi-components of the lexical system discussed directly or indirectly in this volume.

REFERENCES

Aaron, P. G. and Joshi, R. M. (eds.): 1989, *Reading and Writing Disorders in Different Orthographic Systems*, Kluwer Academic Publishers, Dordrecht.

Adams, M. J.: 1979, 'Models of word recognition', *Cognitive Psychology* **11**, 133–176.
Boden, M. A.: 1989, *Artificial Intelligence in Psychology*, The MIT Press, Cambridge, MA.
Caramazza, A.: 1991, *Issues in Reading, Writing and Speaking: A Neuropsychological Perspective*, Kluwer Academic Publishers, Dordrecht.
Chase, C. H. and Tallal, P.: 1990, 'A developmental, interactive activation model of the word superiority effect', *Journal of Experimental Child Psychology* **49**, 448–487.
Chomsky, N.: 1955/1975, *The Logical Structure of Linguistic Theory*, Plenum Press, New York.
Chomsky, N.: 1981, *Lectures on Government and Binding*, Foris, Dordrecht.
Culicover, P.: 1985, 'Learnability explanations and processing explanations', *Natural Language and Linguistic Theory* **2**, 77–104.
Frost, R. and Katz, L. (eds.): 1992, *Orthography, Phonology, Morphology, and Meaning*, North-Holland, Amsterdam.
Kuhn, T. S.: 1970, *The Structure of Scientific Revolutions* (2nd edition, enlarged), University of Chicago Press, Chicago.
Luelsdorff, P. A.: 1991, *Developmental Orthography*, John Benjamins, Amsterdam.
McClelland, J. L. and Rumelhart, D. E.: 1981, 'An interactive activation model of context effects in letter perception: Part 1. An account of basic findings', *Psychological Review* **88**, 375–407.
McClelland, J. L. and Rumelhart, D. E.: 1988, *Explorations in Parallel Distributed Processing: A Handbook of Models, Programs, and Exercises*, The MIT Press, Cambridge, MA.
Minsky, M. L.: 1987, *The Society of Mind*, Simon and Schuster, New York.
Rumelhart, D. E.: 1977, 'Toward an interactive model of reading', in S. Dornic (ed.), *Attention and Performance VI*, Lawrence Erlbaum, Hillsdale, NJ, pp. 573–603.
Rumelhart, D. E.: 1989, 'The architecture of mind: A connectionist approach', in M. I. Posner (ed.), *Foundations of Cognitive Science*, The MIT Press, Cambridge, MA, pp. 133–159.
Seidenberg, M. S.: 1992, 'Connectionism without tears', in S. Davis (ed.), *Connectionism: Theory and Practice*, Oxford University Press, New York, pp. 84–122.
Seidenberg, M. S.: 1993a, 'Connectionist models and cognitive theory', *Psychological Science* **4**, 228–235.
Seidenberg, M. S.: 1993b, 'A connectionist modeling approach to word recognition and dyslexia', *Psychological Science* **4**, 299–304.
Seidenberg, M. S. and McClelland, J. L.: 1989, 'Visual word recognition and pronunciation: A computational model of acquisition, skilled performance, and dyslexia', in A. M. Galaburda (ed.), *From Reading to Neurons*, The MIT Press, Cambridge, MA, pp. 255–303.
Seymour, P. H. K.: 1992, 'Cognitive theories of spelling and implications for education', in C. M. Sterling and C. Robson (eds.), *Psychology, Spelling and Education*, Multilingual Matters, Clevedon, pp. 50–70.
Smolensky, P.: 1988, 'On the proper treatment of connectionism', *Behavioral and Brain Sciences* **11**, 1–74.
Tanenhaus, M. K., Dell, G. S. and Carlson, G.: 1987, 'Context effects and lexical processing: A connectionist approach to modularity', in J. L. Garfield (ed.), *Modularity in Knowledge Representation and Natural-Language Understandings*, The MIT Press, Cambridge, MA, pp. 83–108.

PHILIP T. QUINLAN

CONNECTIONISM AND THE NEW ALEXIA

ABSTRACT. The topic of the present paper is the current status of the notion of a mental lexicon containing individual entries for separate words. Initially traditional accounts of the internal representation of words and the empirical justification of these accounts are examined in detail. Central to traditional theory development have been ideas concerning the manner in which knowledge about words is represented, with many theorists positing many different kinds of knowledge stores. Having considered what seem to be basic characteristics of these models, a discussion of the new connectionist framework is included. Many important differences exist although common to both traditional and connectionist accounts is the notion of a lexical pointer. Put briefly, a lexical pointer allows information in one store to be accessed from another. The notion of a lexical pointer is discussed and the ability of distributed representations to act as pointers is also considered.

In closing, it is argued that although differences in representational format are quite evident at the level of implementation, a natural functional characteristic of a system using distributed representation is that of automatic generalisation.

INTRODUCTION

The notion that knowledge about words is contained in a mental lexicon is so basic to much of current psycholinguistic research that it might appear quite odd to worry about its sensibility. The present paper however has been written on the assumption that it is quite reasonable to question traditional ideas about how knowledge about words is represented internally, for as will become clear such an exercise is sensible given the current renaissance in connectionist research. Within the new connectionist framework many alternative ideas about the nature of internal representation are being explored. An overriding aim therefore is to examine traditional and novel ideas about the nature of word knowledge with a view to uncovering possible fundamental characteristics of the underlying representational system.

Initially a brief sketch of some basic terms and concepts will be included by considering Levelt's recent writings (1989). Having completed this, the middle sections of the paper contain an historical perspective of some of the work on the nature of the mental lexicon. This historical perspective provides a context for some of the distinctions Levelt draws. Interestingly though, Levelt's account is only partially justified by the consideration of the previous experimental work. The paper ends with a consideration of some of the recent connectionist research on human single word processing. It is clear that the connectionist research provides a new framework

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for thinking about traditional concepts. Moreover, this new framework has provoked discussion of a novel set of issues that demand serious consideration.

TRADITIONAL VIEWS OF THE INTERNAL REPRESENTATION OF WORDS

One of the most thorough recent treatments of what constitutes a lexical entry is that provided by Levelt (1989). Levelt describes the internal structure of an item in the mental lexicon as consisting of four components: (i) a meaning component that specifies the semantic content of the word, (ii) a syntactic component that specifies the syntactic nature of the word, (iii) a phonological component that specifies the phonological rendition of the word, and (iv) a morphological component that specifies the morphological nature of the word. Levelt proceeds by distinguishing between the lemma and the morpho-phonological form of the lexical entry. Here the meaning and syntactic component define the lemma and the phonological and morphological components define the words morpho-phonological form. Forming a connection from the lemma to the morpho-phonological form is something known as a lexical pointer. To those not acquainted with computer programming, the notion of a 'pointer' is presumably quite opaque, however, there is a direct computer analogy to be drawn here. In a computer's memory data (known as a pointer) can specify the address of where in memory other data resides. A pointer thereby provides access to information stored elsewhere in memory. Although the notion of a pointer is rarely explicitly specified, in many theoretical accounts of word recognition pointers play a vital role.

In setting out his account of what constitutes a lemma, Levelt discusses the example of the word GIVE. According to Levelt the lemma contains the following structures:

conceptual specification: CAUSE (X, (GOposs (Y, (FROM/TO(X, Y)))))
conceptual arguments: (X, Y, Z)
syntactic category: VERB
grammatical functions: (SUBJECT, DIRECT OBJECT, INDIRECT OBJECT)
relations to COMP: none
lexical pointer: 713
diacritic parameters: tense
aspect
mood
person
number
pitch accent

Some of these properties are relatively transparent with the conceptual specification and conceptual argument being akin to formal/computational specification of the meaning of the word (after Schank, 1975). What is not obvious from this is why the lexical pointer should be '713'. The number is arbitrary for the purposes of the example. What is implied though is that the lexical pointer specifies the 'address' of the morpho-phonological form for the lexical entry. The pointer therefore provides access to the morpho-phonological form and the claim is that the lemma and morpho-phonological form are stored in separate parts of the human memory system. Moreover, Levelt argues for two quite separate stores: one for lemmas (or word meanings) and one for more surface characteristics of the word where orthographic, phonological and morpho-phonological information is represented. In addition Levelt is at pains to point out that the information represented in the two stories is structured in type-distinct ways. This accounts for the fact that a word can be related to other words on the basis of meaning, sound, spelling and so on. Different relations specified in the different stores capture these different similarity relations. Accessing the morpho-phonological form from the lemma is achieved via interrogating the lexical pointer.

This completes the sketch of Levelt's account of lexical representation and having introduced many basic concepts, it is now possible to provide a brief historical résumé of some of the central work on single word recognition. This résumé traces the development of thinking about the basic concepts and illustrates how certain important distinctions have been established experimentally.

The Early Beginning of the Mental Lexicon

Rather surprisingly perhaps, it was Treisman (1960), in an early paper on dichotic listening and selective auditory attention, who advanced the idea that each word in a speaker's vocabulary was represented in an internal dictionary or mental lexicon. The central idea was that each word type had a corresponding unique representation in the mental lexicon. The exact nature of such lexical entries was left unspecified but a basic idea was that each type of entry was activated by the occurrence of the appropriate token. By this account a given stimulus was identified as being a token of a given type when the corresponding entry was activated to a particular level. Word recognition, by this account was essentially seen as a process of activating an internal representation or entry in the mental lexicon. Each entry in the lexicon possessed a threshold which specified a critical level of activation and recognition occurred when an entries level of activation reached the specified threshold level. Moreover, across the entries, threshold levels varied. For words that held a particular significance for a given person, their threshold values would be relatively depressed so as to facilitate their recognition. An example here would be the entry for the person's name. The argument was that such entries would need to accrue less activation before being recognised, than would other entries with higher thresholds. Treisman elaborated on this theme by allowing thresholds to be altered by context in real time. According to this view preceding context could lower the thresholds of highly predictable words. This final assumption proved to be central to accounting for word priming effects (see Taft, 1991, for a review).

The general account set out by Treisman was elaborated upon at great length by Morton (1969) who introduced the term 'logogen' as being akin to the earlier notion of a lexical entry. In Morton's original exposition each word type had an associated unique logogen. Logogens were originally put forward as abstract evidence collectors. Each had a threshold and each was activated by input specifying the occurrence of the appropriate tokens of the type. A given word was recognised when the activation of its corresponding logogen reached the threshold value. Most importantly, on each occasion that a logogen's activation reached threshold, the threshold value was temporarily lowered. With the passage of time the threshold value would however tend to return to its original value. It was by allowing threshold values to vary in this manner that Morton was able to derive an account of various word frequency and repetition effects in the literature.

In the original account it seemed appropriate to define the mental lexicon as specifying all of the information relevant to words. This was assumed to include the specification of the acoustic, visual, semantic, articulatory, graphic, etc. nature of the word. As a consequence, the original logogen model may be referred to as a single store model because all information about the words of the language were assumed to be represented in the same store. This fits with the notation that the logogens were assumed to be both abstract and amodal: abstract because the logogens were not defined relative to a particular token occurrence and amodal because the same set of logogens collected evidence from all modalities.

One Lexicon or Several Lexica?

The Split between Orthographic and Semantic Stores

Over the years the central ideas about amodal logogens and a single store became less tenable (cf. Morton, 1982). As Morton (1982) notes, the primary split was between the logogen system and the cognitive system. Put loosely, the logogen system contained the set of logogens and each logogen collected evidence from the auditory and visual modalities. Separate from this system was the cognitive system. The cognitive system was defined as the repository of all semantic knowledge. Connections were said to exist between the cognitive and logogen systems. This allowed the logogens to accrue activation from the cognitive system in the same way that they accrued evidence from auditory and visual modalities. In this way 'context' could be seen to influence word recognition in addition to the sense-data. The division between the logogen system and the cognitive system bears something of a loose analogy to Levelt's lemma/morpho-phonological form distinction.

Quite independently of Morton's line to inquiry, an early experimental paper on the distinction between orthographic and semantic knowledge was written by Loftus and Cole (1974). The paper bolstered the claim of separate stores of orthographic and semantic representations. Loftus and Cole carried out reaction time (RT) experiments and their second experiment subjects were presented with two kinds of trials. On Adjective-first trials subjects were presented with a triple such as ANIMAL-SMALL-M. The experimenter spoke the category label first and then presented the adjective SMALL in the first field of a multi-channel tachistoscope. After 1/2 s this field was replaced with a second showing the letter M. Subjects had to respond under RT conditions with the name of a small animal whose name began with the letter M (e.g., MOUSE). On Letter-first trials the subjects task was the same although the order of the letter and the adjective was reversed. The results were clear-cut in showing a large and significant difference in RTs to the two sorts of trials: the mean RT for the Adjective-first trials was 1.00 s and the corresponding mean for the Letter-first trials was 1.45 s.

This pattern of results is important not least because they do not gell with the idea that semantic and orthographic information is represented internally in a single store. On the single store account there is no reason why the order of the adjective and the letter should have had any effect in the Loftus and Cole task. There is no reason why accessing a name should be longer in the Letter-first trials than in the Adjective first trials. So in order to account for their data Loftus and Cole argued that separate stores are necessary. In this account two stores were posited: a dictionary store and a semantic store. In the dictionary store the phonemic and orthographic specification of each entry was coded and Loftus and Cole added that each entry acted as a 'pointer' to the 'address' where the appropriate semantic information could be found.

In the Loftus and Cole model therefore pointers were included in the dictionary specification of the words to the end that a dictionary entry could also 'point to' the relevant semantic entry. In addition (although this is not spelt out in their paper), whereas the entries in the dictionary were stored alphabetically, the semantic store was said to be a complex network of interconnected concepts and categories. By extension therefore the model could account for the different orthographic and semantic similarity relations that exist between words. Again this accords well with Levelt's ideas.

In order to account for the pattern of RTs in their second experiment Loftus and Cole developed an explanation in terms of the dictionary-network model. They argued that regardless of whether the adjective or the letter occurred first, the first step in the name retrieval process was to enter the noun category (specified in the semantic network). In the case where the adjective did occur first, all instances in the net that fitted the description became activated and excitation spread out from these instances towards the dictionary store. As a consequence corresponding name representations in the dictionary became activated and when the letter was presented a simple checking process enabled an appropriate name to be uttered.

Different scenarios were envisaged when the adjective was presented second, though. One possible explanation was that subjects waited until the adjective was presented before doing anything: hence the RT penalty on Letter-first trials. An alternative idea was that when the letter was presented activation spread from all noun instances in the semantic store towards their corresponding name representations in the dictionary. Dictionary entries could then be eliminated on the basis of the identity of their initial letter. However, when the adjective was presented activation must then spread back from the dictionary to the semantic net. A response could then be made when an appropriately activated instance in the semantic net was again accessed.

For present purposes, the import of Loftus and Cole's study is that the data are fully compatible with the idea that orthographic and semantic knowledge resides in separate places: a view espoused independently by Morton.

More Detailed Ideas about the Morpho-Phonological Form

Later developments to the Morton's logogen model were motivated by a number of robust priming effects which were observed both within and between the different modalities. Although priming effects are many and varied the basic idea is that one stimulus acts as a prime for another target stimulus. Typically the prime occurs prior to the target and it is the influence of the presentation of the prime on performance with the target that is of main concern. For instance, Murrell and Morton (1974) showed that prior presentation of the word SEEN facilitated subsequent processing of the word SEES almost to the same degree as did the prior presentation of the word SEES itself. In this case, subjects initially read a series of prime stimuli and then carried out a perceptual report task with the target stimuli. In the report task the visual duration threshold was measured for each target word for each subject under tachistoscopic conditions. Importantly, when primed by SEEN the threshold to the target SEES was lowered relative to when the prime was the morphologically unrelated word SEED. This pattern of results was taken to reflect the fact that the logogens were abstract morphological structures sensitive to related groups of morphemes. Given this, the original idea that a particular logogen existed for each word type was seen to be no longer tenable. A separate logogen was now believed to exist for each group of morphemically related words.

An alternative view of the orthographic/morphological nature of lexical representations however, has been developed over several years by Taft (1979, 1982, 1984, 1987). Central to this account of the lexicon is the BOSS or Basic Orthographic Syllabic Structure. Recently Taft has defined the BOSS as being "the first part of the stem or the morpheme of the word, up to and including all consonants following the first vowel, but without creating an illegal consonant cluster in its final position" (Taft, 1987, p. 265). Two strands of evidence have been used to support the psychological validity of the BOSS. Firstly, the evidence comes from how subjects process nonwords. For instance, nonwords that form the BOSS of a real word (e.g., TRAUM of TRAUMA, SPAD of SPACE, etc.) take longer to classify as being nonwords than do other nonword controls. Here the nonword controls formed the beginnings of real words (e.g., SCOUN of SCOUNDREL, BLEN of BLEND) but were not BOSSES in themselves. In addition, nonwords beginning in real words (e.g., LENDY) and nonwords that begin with a BOSS (e.g., MURDY) were slower to classify than were nonwords that fell into neither of these categories (e.g., MALDY).

The second line of evidence comes from performance with real words. Taft (1979) used a paradigm where the letter strings were divided into two letter clusters. However the division between the two clusters was systematically altered. Taft found that when the division occurred after the BOSS boundary (e.g., LANT/ERN), responses were faster than in the case where the division occurred after the first phonological syllable (e.g., LAN/TERN). This was taken as showing that the BOSS division was of more psychological importance than was the syllable division. Indeed Taft (1979) put forward a model of lexical representations where the BOSS plays a primary role. Here the central idea is that there are in fact two internal listings of orthographic strings. In the first there is a complete listing of legal BOSSes. This is in addition to a complete listing of lexical entries which specify the complete orthographic representation of words. By this account, an early stage in word recognition is something called decomposition. During decomposition all affixes are stripped from the input string to reveal the BOSS. This BOSS is then matched against the stored counterpart in the BOSS Listing. Upon a match, the BOSS then activates a base word in the full lexicon and search for the complete string proceeds in a serial fashion from this base string. In the model, the lexicon proper was organised around clusters of words that shared the same BOSS (e.g., FINAL, FINISH, FINITE, INFINITE, DEFINE, CONFINE, REFINE).

Further evidence regarding the abstract lexical representation of word structure has been reported by Taft (1984). Taft was particularly interested in words which are morphemically related but where the common morphemes are pronounced quite differently (e.g., TELEGRAPH, TELEGRAPHY). According to him such words are, at the morpho-phonemic level, represented by the same underlying structure, i.e. #telegraef#. In addition, the correct pronunciation is derived from the morpho-phonemic representation by the application of rule. The general thrust of the argument however concerned the representations of different sorts of homophones. According to Taft the words FINED and FIND have different lexical (i.e., morpho-phonemic) representations, respectively, #fin#d and #find#. FIND comprises a single morpheme whereas FINED comprises two morphemes. In contrast, other homophones are specified relative to the same underlying morpho-phonemic representations, e.g., HEELED and HEALED share the same underlying morpho-phonemic representation namely, #hel#d. To test these ideas Taft developed a homophone detection task in which subjects had to respond on an instance-by-instance basis, where a given visually presented string was a homophone or not. Taft reasoned that in this task homophones like HEALED/HEELED should be responded to more accurately than should homophones like FINED/FIND because in the former case both are defined relative to the same unique underlying representation. Such predictions were borne out by the results: whereas subjects were 28% correct with the FINED/FIND instances they were 78% correct with the HEALED/HEELED instances.

Taft used this evidence to support his view that there is a single abstract lexical representation that underlies both spelling and pronunciation. In particular he has argued that the results suggest that overt pronunciations are derived from more abstract representations that are morphophonemically structured.

The Split between Input and Output Lexica

The next modification to Morton's model arose because of the work of Winnick and Daniel (1970). They showed that naming a picture of a butterfly or saying the word in answer to a definition did not produce a significant priming effect on the subsequent visual duration threshold to the printed word BUTTERFLY. Morton took this pattern of results to reflect the fact that the facilitation was acting a stage in the system different from one where the phonological codes were being assembled. Such a view gave licence to separating out an input logogen system from an output logogen system. Simply put, the input logogens dealt with word recognition and the output logogens dealt with word production. By this view different mental lexica are seen to exist for the reception and production of language.

The Split between Model-Specific Lexica

Further extensions to the model concerned splitting the input logogen system up according to input modality. Two pieces of evidence were cited to justify this manoeuvre. Firstly, Clarke and Morton (1983) found little priming from an auditory prime onto a visually presented target. Secondly, Jackson and Morton (cited by Morton, 1982) found a similar lack of priming when subjects first made a semantic decision to a visually presented word and then had to recognise the word when presented in the auditory modality. Morton used this evidence to justify the division between an auditory and a visual input logogen system. Now separate lexica are seen to exist for the auditory and visual input modalities.

For some this whole line of reasoning has appeared rather questionable. For instance Allport and Funnell (1981) took issue with the idea that the pattern of priming effects necessarily entailed splitting up the logogen system in the ways described. According to them Morton's interpretation of the various priming effects is that such effects reflect long-lasting changes in threshold values. It is this assumption that demanded positing separate logogen systems such that altering the threshold of one logogen in one system is carried out independently of altering the threshold of the corresponding logogen in another system. However, Allport and Funnell (1981) state that the data "are equally compatible with the view that the facilitation is specific to the pathways of access to logogen units" (p. 405). They continue that if this is accepted then the data do not necessitate claims about separate mental lexica specific to input and output modalities. Allport and Funnell develop their arguments relative to the central idea that the same lexical representations underlie both receptive and productive language abilities though different routes to these representations are said to exist. In addition, they are, however, happy to maintain the distinctions between orthographic, phonological and 'cognitive' lexical representations. For them, however, a central issue is about whether there can be said to be a modality-independent lexicon which houses all information about a word. Allport and Funnell prefer to admit separate lexical systems for phonological, orthographic and cognitive/semantic representations.

Organising the Lexical Entries According to Word Frequency

Another attempt at splitting the lexicon came from further investigations of the word frequency effect in lexical decision. On a given trial in the task subjects are presented with a letter string and have to make a speeded judgement about whether the string constitutes a real word or not. The standard finding in such a task as this is that words that occur very often in the language accrue faster responses than do words that occur rarely (Rubenstein *et al.*, 1970). This is the word frequency effect. Perhaps the most straightforward account of the word frequency effect is that the lexicon is arranged by frequency to the extent that all the entries form a single list and are ordered according to their frequency of occurrence in the language. By this account the frequency effect is easily accounted for by assuming that a serial self-terminating search of the lexicon is enacted whenever a letter string is presented. Staring at the top of the list each entry is interrogated in turn and compared with the input string. A WORD response can be enacted whenever a match is discovered between the input string and a stored counterpart. A NONWORD response can only be made when no such match has been found. Such a simple view is widely recognised to be untenable although the notion of frequency ordered search has been maintained by Forster (1976).

In his extended model the lexicon is defined as a master file which is the repository of the complete specification of each word entry. However, access to this master file is via various 'peripheral access files'. Separate access files are posited for orthographic, phonological and semantic/syntactic information. At a further level of detail the entries within each of the access files are said to be grouped into different bins and within each bin the entries are said to be ordered by frequency of occurrence. The entries are said to be partial descriptions of the various words. Complete descriptions are housed in the master file. All of this is reasonably detailed yet, in other respects the account is rather vague. For instance, a procedure of approximate content addressing is invoked to explain lexical decision. Here some unspecified method is employed to decide the approximate bin location of the input string. Having made this decision the entries within a bin are searched in a serial self-terminating fashion. Upon locating a match a lexical checking procedure is then invoked whereby the input string is compared against the full lexical representation as contained in the master file. Rather than dwell on the obvious deficiencies of this account, it is more fruitful to consider another account of the organisation of the lexicon.

The Split between Separate Lexica for High and Low Frequency Words?

In making a detailed examination of the word frequency effect, Glanzer and Ehrenreich (1979) developed a two dictionary model in which a division occurs between a listing for all words and a supplementary listing of all high frequency words. Such a model was motivated by certain interesting effects witnessed in lexical decision when words were organised and presented in blocks defined by frequency. In these experiments subjects ran through various blocks of trials in two general conditions. In the Pure List conditions the words in a particular block were taken from a particular frequency stratum, i.e., the words were either high, medium or low frequency. In the Mixed List condition all kinds of words were randomly intermixed in each of the blocks of trials. Across these two general conditions an interesting pattern of results was observed. In the Mixed List condition a standard frequency effect was witnessed. RTs to high frequency words were faster than RTs to medium frequency words and both of these RTs were faster than RTs to low frequency words. The pattern of performance in the Pure List condition was slightly different: although RTs were fastest to the high frequency words, RTs to the medium and low frequency words did not differ.

Overall it was comparisons across the two conditions which were of prime interest. Importantly, it was found that RTs to the high frequency words were faster in the Pure than in the Mixed List condition. At the time this result was taken to be strong evidence against a strict serial search of a single frequency order list of all the words in the lexicon: such an account did not seem to be able to explain why RTs to the high frequency words differed across the two conditions. However, Glanzer and Ehrenreich (1979) were able to account for this difference by developing the two dictionary model. Here it was assumed that the subject chose which of the two lists to search first. Put briefly, in the Pure List condition, when the subject realises all the words are high frequency then there will be an overwhelming tendency to search the high frequency list first. Given that such a strategy will tend to produce fast matches, this accounts for the fast RTs in this condition. In the Mixed List condition, however, no similar strategy is appropriate hence relying on searching the high frequency list first is no longer such a useful process. Hence various possibilities are opened up and Glanzer and Ehrenreich discuss several accounts of how the start of the search might be divided between the two sorts of lists.

Further examination of the predictions of the two dictionary model however have not been encouraging. For instance, Gordon (1983), although able to replicate the general pattern of Glanzer and Ehrenreich's findings, arrived at a quite different account of processing. In his account only a single lexicon is posited and he explains performance in terms of a shifting decision criterion across the various conditions in the experiment. Contrary to the predictions of the two dictionary model Gordon found that the RT distributions in the Pure and Mixed List conditions were all unimodal. Such a pattern of results is quite contrary to the predictions of the two dictionary model. For as Gordon argues, according to the two dictionary model in the Mixed List condition, high frequency word searches are a mixture of fast high-frequency dictionary retrievals and slower complete-dictionary ones. In turn low frequency RTs arise from complete dictionary searches, or initial high-frequency dictionary searches followed by successful complete-dictionary ones. This kind of explanation predicts multi-modal RT distributions, yet, in start contrast, Gordon found uni-modal RT distributions throughout.

The brief review of work on single word recognition has provided a sketch of some important distinctions that researchers have posited on the strength of their experimental results. Fundamental to all of this work however is the notion that word knowledge is stored in some place in memory and many ancillary claims have been made about different kinds of knowledge being represented in type-distinct stores. In these accounts assessing the contents of the stores is achieved through the use of lexical pointers. Perhaps a more thorough appreciation of the work can be achieved by now considering some notions of mental representation as set out within the new connectionist framework. As will become clear although radical differences do exist between the connectionist and traditional accounts the idea of a lexical pointer is common to both.

NEW CONNECTIONISM AND THE INTERNAL REPRESENTATION OF WORDS

Having presented a very general review of some of the traditional work that has been carried out in the area of human word recognition it is now possible to examine some consequences of adopting the new connectionist framework. In order to do this it is initially important to describe a particular connectionist model in which various strong claims have been made about the absence of a mental lexicon. The model in question is that described by Seidenberg and McClelland (1989) and has been the subject of much recent interest (see further discussion by Quinlan, 1991; and Hulme *et al.*, 1991). As a consequence only a brief sketch is included here.

The model comprised of three components: a set of 400 orthographic units, a set of 200 hidden units (explained below) and a set of 460 phonological units. The orthographic representation of a given string was given by a variant of Wickelgren's (1969) triples scheme. Words were decomposed and coded into triples of adjacent characters. The example given is that of encoding the word MAKE into **MA, MAK, AKE, KE** (where double asterisks signify a white space). However, it was not the case that a single orthographic unit coded a single triple because a distributed coding scheme was used. Each orthographic unit comprised three slots where each slot could take 10 possible characters. The middle slot took 10 possible characters; the beginning and end slot took 10 letters or 9 letters and a white space. The model was initialised by assigning characters to the units on a random basis. Moreover, when a string was presented to the net many orthographic units were activated simply because any given character triple was encoded by more than one orthographic unit. Each orthographic unit encoded 1000 character triples. So when an orthographic unit was activated it was impossible to say, in the absence of the actual input, which of the possible 1000 character triples was responsible. A similar form of coding employed with the orthographic units was used with the phonological units. The phonological encoding scheme was adapted from an earlier model of word processing set out by Rumelhart and McClelland (1986). The example quoted is that of the phonological representation of the word MAKE being rendered into the phonological triples */**mA/*, */mAK/*, and */AK**/*. The actual phonological encoding was slightly different though, because the constituent phonemes were recoded at the level of phonemic features; i.e. features specifying the place and manner of articulation. At the level of the phonological units the phonemic triples were broken into three slots respectively for the preceding context, the central phoneme and the following context. Each character in turn was broken down into its constituent phonemic features and these lists of features were in turn encoded across a range of 16 different phonological units. Sixteen phonological units were activated for each phonological triple. Again each phonological unit comprised an array form of representation with 3 slots for 11, 10 and 11 features respectively. An example of the featural representation in one phonological unit is [vowel, fricative, stop]. Between the orthographic and phonological layers of units was a set of hidden units. Full connectivity existed between the orthographic units and the hidden units and between the hidden units and the phonological units. Weights on all connections were initialised with small random values and training was carried out with a variant of the back-propagation algorithm (Rumelhart *et al.*, 1986). Here the aim was have the model produce an appropriate pattern of activation across the phonological units whenever a word was encoded by the orthographic units. Having trained the net, the aim was then to see how the model could account for various results in the psycholinguistic literature.

The training regime was reasonably straightforward. On a given trial a word chosen from the target set was presented to the net and immediately encoded by the orthographic units. Activation was then propagated forward to the hidden units, and forward again to the phonological units. Most distinctive though, immediately activation from the orthographic units was received at the hidden units, feedback from the hidden units to the orthographic units occurred. It is the pattern of activity across the hidden units combined with the weight on the links between the hidden units and the orthographic units which is critical. The feedback from the hidden units induces a new pattern of activity across the orthographic units and this in turn can be compared to the original input. Any discrepancy (known as the orthographic error) is then used as an index of changes to the weights on the connections between the orthographic and hidden layers. Activation from the hidden units to the phonological units in turn induces a pattern of activity across the phonological units. This is then compared against the desired phonological pattern of activation and any discrepancy (known as phonological error) is used to alter the weights on the connections between the hidden and phonological layers. If this particular training regime is to be taken literally it suggests that learning to read consists of producing an utterance in the presence of a teacher who then provides feedback in the manner of the correct pronunciation. This particular view of learning to read seems to fit well with actual teach practices.

In the main the corpus of words used in training were uninflected, monosyllables of three or more letters selected from the Kučera and Francis (1967) word-count. Other words not listed in the word-count were also added to the input corpus because they had been used in previous experiments in the literature. An aim was to see whether the model could eventually simulate effects with these words as previously reported in the human reading literature. The number of words in the training set was 2897; however, not all words were presented equally often. Words in the set were presented to the net a number of times proportionate to the log of their frequency of occurrence in the language. (Real frequency counts range from 0 to several tens per million.) Taking the log of the frequency compressed the range of number of presentations of the words. This was justified on the grounds that it reduced the variation of presentations of the different words and that it in turn allowed a sensible number of iterations of the training regime to be completed. A number of reasons were given in defence of the psychological plausibility of this manoeuvre: a main one being that the large spread of frequency values in the norms is a gross overestimate of the range of frequencies which occur in a child's early language experience. Overall the net was trained on 150,000 learning trials.

Following training, Seidenberg and McClelland then went on to use the net to explain performance in many different word processing tasks. The manner in which they did this is again instructive. The general method was to present words to the adult net and compute the orthographic and phonological error scores. The orthographic error scores were then used as an index of performance in lexical decision tasks; the phonological error scores were used as indices of performance in naming tasks. Seidenberg and McClelland define an phonological error score as the sum of the squared differences between the actual activation for each phonological unit and its counterpart in the desired pattern of activation. The orthographic error score was defined in a similar manner with respect to the input string and to the orthographic units. To take just one example, Seidenberg and McClelland used the phonological error score as an index of naming performance with the words taken from a study by Taraban and McClelland (1987). The actual human data (i.e., naming RTs) showed a significant frequency by regularity interaction – although high frequency words were overall named faster than low frequency words, this difference was greater for regular words than irregular words. When the model was presented with comparable sets of high and low frequency regular and irregular words, it was seen to behave in a comparable way. Here performance was assessed by plotting the phonological error score for each of the four kinds of words. The data from the simulation showed a frequency by regularity interaction taken to be analogous to that witnessed in the human data. This is just one of many startling results that Seidenberg and McClelland report in detail.

Of the many aspects of the model that might form the basis for discussion one claim will be focussed on here. This is that Seidenberg and McClelland state that the model does not contain a lexicon. Given the traditional views about lexical representation discussed above it is indeed true that nowhere in the model are there units (functional or actual) that correspond to words. For instance, nowhere in the model is there a uniquely identifiable unit that becomes activated when a word is presented. In this sense therefore the model is quite unlike traditional accounts that posit *localist* representations of words. For instance, in the Loftus and Cole model words are represented as particular entries in the mental lexicon and in the semantic network component of their model each entry is represented by a particular node in a semantic net. It is this idea of 'one node/unit for one representation' that is central to model being predicated on the notion of localist representation. Implicit in such accounts is the idea that the representation of a word is found at some particular place in memory (see Quinlan, 1987, 1991, for further discussion of this point). In the Seidenberg and McClelland model, however, there are no such localist representations for words. On the contrary the model uses distributed representations. When a word is presented to the model it is encoded across a subset of the possible input units. Moreover, it is the collective activation of a number of units that constitutes the distributed representation of the word. Indeed it is because the model does not possess localist representations of words that Seidenberg and McClelland have argued that the model does not possess a lexicon. It is this claim that forms the basis of discussion in the rest of the paper.

Part of the interest in the claim that the model does not possess a lexicon comes from consideration of the detailed critique set out by Besner *et al.* (1990). They have disputed the claim arguing instead that although there are no lexical entries in the model there are distributed representations that do function as lexical representations (see also Monsell, 1991, p. 162, for a related discussion). According to Besner *et al.* the distributed representations in the model do allow for systematic interactions to take place between the semantic store, the phonological store, and the orthographic store. Such functional roles have traditionally been associated with lexical entries. Indeed such functional roles define lexical pointers as set out by Levelt (1989). However, there are a number of senses in which the model could be said to have lexical representations. For instance, different final states of the whole net stand for different words. In this sense therefore the net does possess different representations for the different words. Alternatively it might be argued that different final states of the input units correspond to orthographic representations of different words and different final states of the output units correspond to phonological representations of different words. Therefore it might be argued that the model does possess independent orthographic and phonological lexica. So although the model does not utilise localist representations, its distributed representations do fulfil the functions traditionally associated with lexical entries. Yet there is also an interesting sense in which distributed representations can be seen to fulfil the role of lexical pointers. For example, the presence of a particular distributed pattern of activity over the input (orthographic) units in Seidenberg and McClelland's model gives rise to the appropriate distributed pattern of activity over the output (phonological) units. In this sense therefore the distributed orthographic representation is seen to access the distributed phonological representation.

It may well appear that, at this level of analysis, the differences between distributed and localist representational schemes are of little import. Indeed as Broadbent (1985) has argued much of this kind of debate seems to have consequences only at the implementational and not the computational level of analysis. Here the distinction is between specifying the goals and logic of the system and how these might be instantiated in the brain, i.e., specifying which 'computational modules that make up the system and the exact way in which those modules are implemented' (p. 189). According to Broadbent arguments that range over the nature of the underlying representation (i.e., whether it be localist or distributed) concern purely the level of implementation and are quite separate from issues at the computational level. However, upon reflection such a claim cannot be sustained for there is a sense in which choosing between localist and distributed systems does have important consequences at the computational level.

Consider the sorts of input and output representations used in the Seidenberg and McClelland model. Both the orthographic and phonological units implement something known as coarse coding. In coarse coding schemes (Hinton *et al.*, 1986) each unit codes many instances and many features activate each unit. For example, each input unit encodes 1000 letter triples and up to 30 different letter-positions features activate each unit. A similar coarse coding scheme exists for the phonological units.

As a consequence, both input and output units coarse code information. Importantly, the signature of a coarse coding scheme is that it allows for something known as automatic generalisation to arise naturally. Put briefly, what is learnt for one instance automatically generalises to all other instances within the appropriate representational set. In the Seidenberg and McClelland model, whatever is learnt regarding one of the 1000 input triples automatically generalises to the other 999. Such automatic generalisation is a property that arises through using coarse coded distributed representations. Automatic generalisation does not emerge naturally out of systems comprising localist representations (see Hinton *et al.*, 1986, for a more complete discussion of this point). So the general point is that automatic generalisation is a functional property of a system comprising distributed and not localist representation. The general and simple point is that how representations are implemented can have profound consequences at the computational level.

CONCLUDING COMMENTS

It is fitting to conclude by reiterating some points made by Duncan (1985) in the context of discussing the seemingly distant topic of visual attention. Duncan poses the question, "What does it mean to ask whether information has been 'analyzed' or 'identified' at some stage?" (p. 101), and concludes that "when psychologists ask whether information is or is not 'analyzed' ..., their experiments rest on showing that information can or cannot be used in a particular way". It is the idea of putting information to use which has been so neglected in the literature on word recognition. Without addressing issues about what basic functions the human word processor fulfils, it is easy to see how traditional theory development lost its way. It seems that the quest for drawing distinctions between different 'linguistic stores' seemed to exist in the absence of any clear idea about what functions they might subserve. Such a view fits well with an argument put forward by Henderson (1987). According to Henderson (1987) a major shift in emphasis occurred when words were no longer considered as being merely visual patterns. The 'new look' approach accordingly treated word recognition "as the interface of the perceptual to the linguistic domain" (p. 193). By this Henderson means that, "Successful identification of a word as a visual pattern is not the natural terminus of cognitive activity but a preliminary to morphological, phonological, logical, semantic and syntactic processing" (p. 195). Whether or not the new connectionist framework can provide useful insights into mental *processing* remains to be seen.

REFERENCES

Allport, D. A. and Funnell, E.: 1981, 'Components of the mental lexicon', *Philosophical Transactions of the Royal Society of London, Series B* **295**, 397–410.

Besner, D., Twilley, L., McCann, R. S. and Seergobin, K.: 1990, 'On the connection between connectionism and data: Are a few words necessary?', *Psychological Review* **97**, 432–446.

Broadbent, D. E.: 1985, 'A question of levels: Comment on McClelland and Rumelhart', *Journal of Experimental Psychology: General* **114**, 189–192.

Clarke, R. and Morton, J.: 1983, 'Cross-modality facilitation in tachistoscopic word recognition', *Quarterly Journal of Experimental Psychology* **35A**, 79–96.

Duncan, J.: 1985, 'Visual search and visual attention', in M. Posner and O. S. M. Marin (eds.), *Attention and Performance, XI*, Lawrence Erlbaum Associates, London, pp. 85–105.

Forster, K. I.: 1976, 'Accessing the mental lexicon', in E. C. J. Walker and R. J. Wales (eds.), *New Approaches to Language Mechanisms*, North-Holland, Amsterdam, pp. 257–287.

Glanzer, M. and Ehrenreich, S. L.: 1979, 'Structure and search of the internal lexicon', *Journal of Verbal Learning and Verbal Behavior* **18**, 381–398.

Gordon, B.: 1983, 'Lexical access and lexical decision: Mechanisms of frequency sensitivity', *Journal of Verbal Learning and Verbal Behavior* **22**, 24–44.

Henderson, L.: 1987, 'Word recognition: A tutorial review', in M. Coltheart (ed.), *Attention and Performance, XII*, Lawrence Erlbaum Associates, London, pp. 172–200.

Hinton, G. E., McClelland, J. L. and Rumelhart, D. E.: 1986, 'Distributed representations', in D. E. Rumelhart, J. L. McClelland and the PDP Research Group (eds.), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Volume 1: Foundations*, The MIT Press, Cambridge, MA, pp. 77–109.

Hulme, C., Snowling, M. and Quinlan, P. T.: 1991, 'Connectionism and learning to read: Steps towards a psychologically plausible model', *Reading and Writing: An Interdisciplinary Journal* **3**, 159–168.

Kučera, H. and Francis, W. N.: 1967, *Computational Analysis of Present-Day American English*, Brown University Press, Providence, RI.

Levelt, W. J. M.: 1989, *Speaking: From Intention to Articulation*, The MIT Press, Cambridge, MA.

Loftus, E. F. and Cole, W.: 1974, 'Retrieving attribute and name information from semantic information', *Journal of Experimental Psychology* **102**, 1116–1121.

Monsell, S.: 1991, 'The nature and locus of word frequency effects in reading', in D. Besner and G. W. Humphreys (eds.), *Basic Processes in Reading: Visual Word Recognition*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 148–197.

Morton, J.: 1969, 'The interaction of information in word recognition', *Psychological Review* **76**, 165–178.

Morton, J.: 1982, 'Disintegrating the lexicon: An information processing approach', in J. Mehler, E. C. T. Walker and M. Garrett (eds.), *Perspectives on Mental Representation: Experimental and Theoretical Studies of Cognitive Processes and Capacities*, Lawrence Erlbaum Associates, Hillsdale, NJ, pp. 89–109.

Murrell, G. A. and Morton, J.: 1974, 'Word recognition and morphemic structure', *Journal of Experimental Psychology* **102**, 963–968.

Quinlan, P. T.: 1987, 'Theoretical notes on 'Parallel models of associative memory'' [A commentary on *Parallel Models of Associative Memory*, by G. E. Hinton and J. A. Anderson (eds.), Lawrence Erlbaum Associates, Hillsdale, NJ, 1981], *Cognitive Neuropsychology* **4**, 333–364.

Quinlan, P. T.: 1991, *Connectionism and Psychology: A Psychological Perspective on New Connectionist Research*, Harvester-Wheatsheaf, Hemel Hempstead.
Rubenstein, H., Garfield, L. and Millikan, J. A.: 1970, 'Homographic entries in the internal lexicon', *Journal of Verbal Learning and Verbal Behavior* **9**, 487–494.
Rumelhart, D. E., Hinton, G. E. and Williams, R. J.: 1986, 'Learning internal representations by error propagation', in D. E. Rumelhart, J. L. McClelland and the PDP Research Group (eds.), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 1: Foundations*, The MIT Press, Cambridge, MA, pp. 318–362.
Rumelhart, D. E. and McClelland, J. L.: 1986, 'On learning the past tense of English verbs', in J. L. McClelland, D. E. Rumelhart and the PDP Research Group (eds.), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 2: Psychological and Biological Models*, The MIT Press, Cambridge, MA, pp. 216–271.
Schank, R. C.: 1975, *Conceptual Information Processing*, North-Holland, Amsterdam.
Seidenberg, M. S. and McClelland, J. L.: 1989, 'A distributed, developmental model of word recognition and naming', *Psychological Review* **96**, 523–568.
Taft, M.: 1979, 'Lexical access via an orthographic code: The Basic Orthographic Syllabic Structure (BOSS)', *Journal of Verbal Learning and Verbal Behavior* **18**, 21–39.
Taft, M.: 1982, 'An alternative to grapheme-phoneme conversion rules?', *Memory & Cognition* **10**, 465–474.
Taft, M.: 1984, 'Evidence for an abstract lexical representation of word structure', *Memory & Cognition* **2**, 264–269.
Taft, M.: 1987, 'Morphographic processing. The BOSS re-emerges', in M. Coltheart (ed.), *Attention and Performance, XII*, Lawrence Erlbaum Associates, London, pp. 265–279.
Taft, M.: 1991, *Reading and the Mental Lexicon*, Lawrence Erlbaum Associates, London.
Taraban, R. and McClelland, J. L.: 1987, 'Conspiracy effects in word pronunciation', *Journal of Memory and Language* **26**, 608–631.
Treisman, A. M.: 1960, 'Contextual cues in selective listening', *Quarterly Journal of Experimental Psychology* **12**, 242–248.
Wickelgren, W. A.: 1969, 'Context-sensitive coding, associative memory and serial order in (speech) behavior', *Psychological Review* **76**, 1–15.
Winnick, W. A. and Daniel, S. A.: 1970, 'Two kinds of response priming in tachistoscopic recognition', *Journal of Experimental Psychology* **84**, 74–81.

GORDON D. A. BROWN AND RICHARD P. W. LOOSEMORE

A COMPUTATIONAL APPROACH TO DYSLEXIC READING AND SPELLING

ABSTRACT. This chapter discusses the ability of computational models to improve our understanding of dyslexic reading and writing. Connectionist models of the development of alphabetic reading and spelling in normal and dyslexic children are described. The models learn to associate representations of word pronunciations with spellings. The models learn to read and spell regular words more quickly than irregular items. When the computational resources available to such models are restricted, the models learn more slowly and fail to learn some of the irregular items in their vocabularies. The restricted models behave analogously to developmental dyslexics, and, crucially, have selective deficits with non-word processing although they do not show reduced sound-to-spelling or spelling-to-sound regularity effects. This is consistent with the experimental literature. Experimental evidence is reported that shows that both normal and dyslexic children of various ages have difficulties with reading and spelling particular word types that are similar to the problems experienced by the models on the same words. The good fit between model and data is taken as evidence that, throughout much of the relevant developmental period, the task facing children can be usefully viewed as a statistical one. The level of difficulty posed by particular words in spelling is well predicted by the extent to which those words conform to the relevant regularities of the language. Furthermore, the models resolves an apparent paradox in the experimental literature, for in their dyslexic forms they exhibit a selective deficit in non-word reading and spelling even though they do not show reduced sound-to-spelling regularity effects.

INTRODUCTION

In this chapter we show how recent advances in computational modelling can improve our understanding of the cognitive deficits associated with developmental dyslexia. In particular we focus on the nature of the spelling process in normal and dyslexic children, and describe some of our recent experiments that have studied spelling error rates in dyslexia. We argue that computational modelling can resolve apparently contradictory research findings in the dyslexia literature on both reading and spelling. The plan of the chapter is as follows. First, we discuss the demands of the spelling process and current psychological models of the normal development of spelling. We then describe the attempts that have been made to characterise the nature of the spelling deficit in dyslexia in terms of these cognitive psychological models. In the next part of the chapter we go on to describe the class of computational models called 'connectionist' or 'parallel distributed processing' models. We illustrate this approach with

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particular reference to a recent connectionist model of the development of reading (Seidenberg and McClelland, 1989a, 1989b) and show how this model provides an alternative way of looking at dyslexics' problems in reading (Seidenberg, 1989). We also describe our own investigations of the performance of a similar connectionist model of reading, and argue that the connectionist approach sheds new light on empirical data that are otherwise difficult to interpret. Next, we describe a connectionist model of spelling that we have developed (Brown *et al.*, 1992) and describe the model's predictions concerning the types of word that should be particularly difficult for normal and dyslexic children to spell. We then summarise the results of some experiments that test the predictions of the model as applied to developmental dyslexia. The spelling model is analysed in detail, and it is shown that 'dyslexic' versions of it exhibit a selective deficit in non-word processing. This is consistent with recent experimental work, which has generally found selective deficits in non-word processing in dyslexia even though reductions in regularity effects are not normally apparent in group studies. In the final part of the chapter we discuss the implications of the approach for our understanding of normal and dyslexic spelling development. We argue that the connectionist approach is a useful one and that it can provide a novel way to address some theoretical issues in the domain of dyslexia research. In particular we conclude that much of dyslexics' observed performance can be characterised in terms of a shortfall in the computational resources available for reading and spelling acquisition.

We begin with spelling, as this forms the main focus of the present chapter. However, many of the conclusions apply to reading as well as spelling, and we shall try to bring this out throughout the chapter.

The Nature of Spelling

Many English words can be correctly spelled on the basis of their pronunciation. However, the use of pronunciation alone is an unreliable method of deriving spellings. Some words are pronounced the same as other words, but spelled differently (non-homographic homophones: HARE–HAIR; THEIR–THERE). Other words, such as SOAP, are not spelled as might be expected from their pronunciations – cf. HOPE, COPE, ROPE, etc. It is of course theoretically possible that pronunciation information is not used at all in spelling. There is, however, ample empirical support for the claim that pronunciation information is used in both children's and adults' spelling. Any satisfactory model must reconcile these two sets of constraints.

Psychological Models of Spelling

Descriptive approaches to spelling development often assume that the early ('logographic') stages of learning to write involve acquiring the visual forms of a small number of items. In this stage sub-lexical structure is not used. In subsequent development the child gradually becomes aware of this structure and uses it to develop a sound-to-spelling translation routine. This is 'alphabetic' spelling. Such a routine can cope with regular but not irregular words. Finally comes what Frith (1985) terms 'orthographic' processing: this involves the "instant analysis of words into orthographic units without phonological conversion" (1985, p. 306).

Skilled readers thus have alternative strategies for spelling words available to them. One routine makes use of sound-to-spelling translation 'rules' of some kind, although there is considerable debate about the representations that these rules operate on (e.g. Barry and Seymour, 1986; Campbell, 1985). The 'direct' routine provides a one-to-one mapping from particular lexical entries to representations of their spelled forms. This routine is used for words which cannot be reliably spelled on the basis of their pronunciations. Recent models typically contain other components such as a graphemic output buffer (e.g. Caramazza *et al.*, 1987).

Frith (1985) suggests that classical developmental dyslexia can be characterised as an arrest at her 'stage 1' during which writing is logographic. Sound-to-spelling translation routines do not develop, except perhaps as a result of careful individual tuition, and the child is left with a mechanism that can only deal with words as wholes, and which is not sensitive to sub-lexical regularities. This view of developmental dyslexia as arrest at the logographic stage leads to a number of predictions. For example, the lack of translation routines should lead to a selective difficulty in reading or spelling non-words, and also to reduced or absent spelling-to-sound and sound-to-spelling regularity effects. (This is because such regularity effects reflect the use of the sub-lexical translation routines: regular words will only be advantaged if sound-to-spelling knowledge is available.) Later in the present chapter we describe a study we designed (Brown *et al.*, 1992) to investigate whether dyslexics show a normal regularity effect in spelling. This topic has not been widely studied in spelling, but Barron (1980) found larger sound-to-spelling regularity effects in poor readers, and Seymour and Porpodas (1980) report data which may suggest a smaller regularity effect for dyslexic children on low frequency words. In spelling, as in reading, there is already evidence that dyslexics do have particular difficulty with non-word processing (e.g. Frith, 1980; Jorm, 1981). It should be noted that this approach views dyslexic processing after the time of developmental arrest as abnormal, or 'deviant', rather than merely 'delayed'. We address this issue in more detail below.

The traditional psychological approach outlined above makes frequent reference to 'cognitive-level' concepts such as rules, strategies and developmental stages. The framework has proved successful in characterising both normal and disturbed literacy development, and has lead to much fruitful research. However our own interest is in implementing computational models of these processes. It is our belief that, as Kelvin put it: "I can't really understand something unless I can make a mechanical model of it." Further: we would like to produce a model which *acquires* knowledge of language, to see whether the learning process itself can result in the observed characteristics of skilled spelling. In trying to translate the above models into working implementations, we find that they lack specificity in precisely those aspects needed to produce models which learn. Their strengths lie in their descriptive coverage of the data, rather than in their provision of a low-level causal account of the mechanisms that mediate the acquisition of literacy.

Connectionism

An alternative approach is provided by 'connectionist' or 'parallel distributed processing' models of psychological processes. The emphasis here is not on high-level concepts such as rules or strategies; rather, such models can learn to associate pairs of patterns without reference to explicit rules. For example, the recent model of Seidenberg and McClelland (1989a) learns to associate the orthographic forms of words to their corresponding phonological forms.

A connectionist network consists of a large number of computational units whose behaviour is in some respects akin to that of neurons. Each unit has connections to some, although generally not all, of the other units in the network. Associated with every unit is a quantity called the 'activation' level of that unit. The main purpose of a connection is to communicate the activation level of one unit to another. The activation level is modified as it passes through a connection, depending on the 'strength' of that connection. The level of activation of each unit is determined by the sum of all the modified activations that it receives from other units that it is connected to. Broadly speaking, a unit's activation level is proportional to the amount that the total activation coming into the unit gets over a 'threshold' value. The amount of influence that one unit has on another (if they are connected) depends on both the size of its own activation level, and the strength of the connection between the two units.

Such networks have a number of interesting computational properties. Some units in the network can be considered 'input' units, while others are 'output' units. The activation levels of the set of input units can be thought of as a pattern which represents something meaningful, such as the phonological form of a word. Likewise, the pattern formed by the activation levels of the output units may be regarded as a representation of, for example, the spelled form of a word. When an input pattern is imposed on the input units, activation will spread through the connections in the network until some pattern of activity is established on the output units. The precise pattern formed on the output units will depend on the strengths of all the connections in the network. The fundamental property of a connectionist network is that given a particular input pattern, the connection strengths can change themselves in such a way as to cause a particular pattern to appear on the output units in response to an input pattern. In this way, the network can learn to associate one pattern with another. Moreover, a network is not confined to representing just one input-output pair; rather, a number of associations between pairs of patterns can be learned within the same set of connections.

It is important to emphasise that the network learns about associations between pairs of patterns simply by being repeatedly exposed to the pairs: all of the learning takes place by slow modification of connection strengths in the course of 'experience'. At the end of learning the network is able to produce the correct output pattern in response to a particular input.

It is this learning ability which has led to a widespread interest in these models within psychology, for it is possible to examine the performance of the network as it encodes a set of associations over time. Connectionist networks have been used to provide psychologically interesting models of a variety of different behaviours, such as verb tense learning, speech perception and speech production. In the present chapter we focus on the application of connectionist techniques to the modelling of literacy development.

Early network models of reading (Brown, 1987; McClelland and Rumelhart, 1981) lacked any ability to learn associations for themselves. This limited the size of vocabulary they could work with, for all the connection strengths had to be determined 'by hand'. One more recent and highly influential model of reading has been developed by Seidenberg and McClelland (1989a). This model works using the principles outlined above – it learns to associate input representations of word orthography with output representations of word pronunciations. Using a standard connectionist learning procedure it learns to produce the correct pronunciation of nearly 3,000 monosyllabic words. Seidenberg and McClelland (1989a) show how this model can account for a very wide range of psychological data from a variety of different experimental paradigms such as lexical decision tasks and single word naming. The model learns to abstract some of the general statistical regularity and redundancy that is present in the relationship between orthography and phonology in English. Indeed, this abstraction of statistical structure is an important general characteristic of connectionist models. This seems to underlie the ability of the model to show spelling-to-sound regularity effects which are very similar to those observed in human performance. These regularity effects are more pronounced for low frequency words, which is the case for human subjects (Seidenberg *et al.*, 1984). In addition, the model is sometimes able to synthesise appropriate pronunciations for novel items (non-word naming). Furthermore, Patterson *et al.* (1989) have argued that when the model is 'lesioned' by removing some proportion of its units or connections, its behaviour resembles in many respects that of brain-injured 'acquired dyslexic' patients, in that it has a selective difficulty in reading words which contain irregular spelling-to-sound correspondences. Here we do not summarise the full range of phenomena encompassed by this model, nor do we discuss some recent criticisms of the model (e.g. Besner *et al.*, 1990).

We do, however, wish to focus on two particular properties of the model. The first is its ability to pronounce both regular and irregular words with only one mechanism – it therefore stands in contrast to so-called 'dual-route' models of reading which, analogously to the psychological models of spelling described earlier, assume that two separate routes to pronunciation must be available if both regular and irregular items are to be pronounced successfully. (Note that the full architecture described by Seidenberg and McClelland, not all of which was implemented, does contain two routes.) The second claim that has been made on the basis of this connectionist model of reading concerns its ability to characterise the reading behaviour of developmentally dyslexic children in terms of the computational capacity made available to the network during learning.

To understand how this works, it is necessary to understand that not all of the units in a connectionist network need be either 'input' or 'output' units. Those which are neither input nor output are called 'hidden' units. The model appears to use its hidden units to represent regularities in the corpus of patterns that it sees. Because it is not generally provided with sufficient hidden units to enable it to learn all the required associations on a one-to-one basis, it must choose economical representations such that it can encode many patterns over a few units. The capacity of the model to do this will depend upon the number of hidden units available. The connectionist model that Seidenberg and McClelland used to examine skilled adult reading was given 200 hidden units. Providing the model with only 100 hidden units (reducing its computational capacity) resulted in a general reduction in performance for all word types (regular and irregular, high and low frequency). The model with reduced computational resources showed spelling-to-sound regularity effects for both low frequency and high frequency words, whereas the larger model, like skilled adult readers, only showed a regularity effect for the low frequency words. Seidenberg and McClelland (1989b) argue that this is similar to the difference between good and poor young readers, for poorer readers show spelling-to-sound regularity effects for both high and low frequency words, whereas good readers only show regularity effects for low frequency items.

It is therefore possible to argue that poor reading can at least partly be described in terms of a limitation in the computational resources available to the model during learning. Note that this represents a different way of looking at reading problems from the traditional debate, which is couched in terms of whether reading is 'deviant' or 'delayed'. The behaviour of the model with restricted computational resources cannot adequately be described as simply 'delayed' or 'deviant'. One way of characterising the delay hypothesis of reading disorders is to say that dyslexics read 'in the same way as' younger non-dyslexics. In this respect the model appears to conform to a delay view of reading disability. However, it is also the case that the dyslexic model shows regularity effects when the non-dyslexic model does not (i.e. on high-frequency words). In the traditional information processing framework the presence of regularity effects in one group but not another would be taken as evidence for qualitatively different (i.e. 'deviant') processing. More specifically, the presence of regularity effects would be taken to indicate a failure to move from alphabetic to orthographic processing. Yet it appears non-sensical to interpret the dyslexic model as employing a qualitatively different processing strategy simply because it has fewer computational resources available to it. It therefore seems that the mere presence or absence of spelling-to-sound regularity effects cannot be taken as evidence for or against the use of a particular processing strategy. We return to discussion of this issue below.

It is not claimed of course that the connectionist approach and the variations in network capacity can account for the whole range of dyslexic symptoms. Nevertheless, in terms of the regularity effects, which provide one of the main indicators of which stage a child is at in reading, the connectionist model of reading can account for a wide range of relevant empirical data.

Reading, Connectionism and Dyslexia

An obvious further question is, therefore, whether the connectionist approach to reading development can account for the full range of experimental evidence from the study of developmental dyslexia. In the case of reading as for spelling, the majority of experimental work has been directed towards the 'delay' and 'deviance' accounts of dyslexia. As we described earlier in the context of spelling, the phonological deficit hypothesis leads to two critical predictions about experimental tasks that should cause particular difficulty for dyslexic children in reading. The first of these concerns the reading of non-words. Because a non-word (e.g. SLINT) can only be pronounced by using spelling-to-sound rules or analogies, non-word reading provides a test of spelling-to-sound decoding ability. Therefore, if dyslexics have specific decoding problems, they should perform worse at non-word reading than non-dyslexics. This prediction can be tested by comparing the performance of dyslexic children with younger non-dyslexic children who are reading at the same level. (The rationale behind this design is that it allows tests of whether a given level of reading skill is achieved by the same or different strategies in different populations. If dyslexic and non-dyslexic children of the same *chronological* age were compared, in contrast, then any group differences could be due to the smaller amount of reading practice experienced by the dyslexic children – differences could be a *consequence* rather than a *cause* of the reading delay.)

Rack *et al.* (1992) review considerable evidence that developmental dyslexics do have difficulty in non-word reading or repetition when compared with control subjects reading at the same level (e.g. Bradley and Bryant, 1981; Frith and Snowling, 1983; Seymour and Porpodas, 1980; Snowling, 1981; Snowling *et al.*, 1986). However, we have argued elsewhere that the majority of studies that have looked for reduced effects of spelling-to-sound regularity in reading have found equivalent regularity effects in dyslexics and controls (e.g. Brown and Watson, 1991). Thus several studies have found equivalent spelling-to-sound regularity effects in dyslexic reading (e.g. Baddeley *et al.*, 1988; Beech and Harding, 1984; Brown and Watson, 1991; Seidenberg *et al.*, 1985; Szeszulski and Manis, 1987; Treiman and Hirsh-Pasek, 1987; Watson and Brown, 1992) but relatively few have found reduced regularity effects (Barron, 1980; Frith and Snowling, 1983). This represents a somewhat contradictory set of findings, for if dyslexics are indeed impaired at alphabetic processing one should find both non-word difficulty *and* reduced regularity effects in both reading and spelling.

To explore this paradox further, we examined regularity effects and non-word processing in a connectionist model of reading (Brown *et al.*, 1993). This was essentially a smaller and simplified version of the model described by Seidenberg and McClelland (1989a). The network learned to associate word pronunciations with corresponding orthographic representations using the 'backpropagation' gradient descent learning algorithm (Rumelhart *et al.*, 1986), as in the Seidenberg and McClelland model. Words were represented as activations of 'triples' of phonemes or letters. The orthographic form of a word such as HAVE, for example, would be represented by the four triples _HA + HAV + AVE + VE_ (where the '_' character signifies a word boundary). Although this scheme cannot represent all words (Prince and Pinker, 1988) it suffices for the vocabulary of our model. Choice of representational scheme may not be critical provided sufficient sub-lexical structure is captured. Pronunciations were represented as distributed patterns of activation over 50 'output' units – each output unit participated in the encoding of 24 of the phoneme triples. Orthographic patterns were represented over 50 'input' units in a similar way. The input units and output units were connected via an intermediate layer of 'hidden units'. The number of hidden units was varied in order to vary the computational resources of the network in an attempt to model dyslexic performance. There were three versions of the model: 'normal' (35 hidden units); 'mildly dyslexic' (20 hidden units), and 'severely dyslexic' (15 hidden units). The model was given a vocabulary of 19 regular words, 19 irregular words, and 189 other words selected so as to render the critical items regular or irregular for the model. For example, the irregular word PINT was accompanied in the vocabulary by enemies MINT, HINT, and TINT. The performance of the model was assessed in terms of the 'summed squared error score' to each item as it changed during learning. This error measure represents the difference between the target and the actual pronunciation for each association the network was required to learn.

The results suggested that the early stages of learning in a model with relatively high computational resources are qualitatively similar to later learning in the models with restricted resources. Thus when the behaviour of the network is assessed in terms of its performance on regular and irregular items, the 'dyslexic' versions of the model show delayed rather than deviant performance – the models all showed the same relative difficulty on the different item types (irregular items giving rise to a higher error score), but the 'dyslexic' versions of the model, with reduced computational resources, learned more slowly. This is consistent with the results of the experimental evidence described above, which has generally found equivalent-sized regularity effects in dyslexic children and younger non-dyslexic children.

However, we noted above that empirical research in dyslexia has reached a different conclusion when non-word reading is used as the performance measure. We therefore examined non-word processing in the three versions of the reading model. Non-words were derived from each regular and irregular word by changing one of the word's consonants (e.g. YILL; MAVE). Non-word performance was assessed by presenting the model with phonological representations of non-words and examining the error score for the 'correct' (regular) pronunciation of the non-words. Differences in regularity effects and non-word processing were then examined in the dyslexic and non-dyslexic models. An analogue to a reading-age control experiment was carried out by taking the three models at the point in learning at which they all had an equal error score to regular words. This

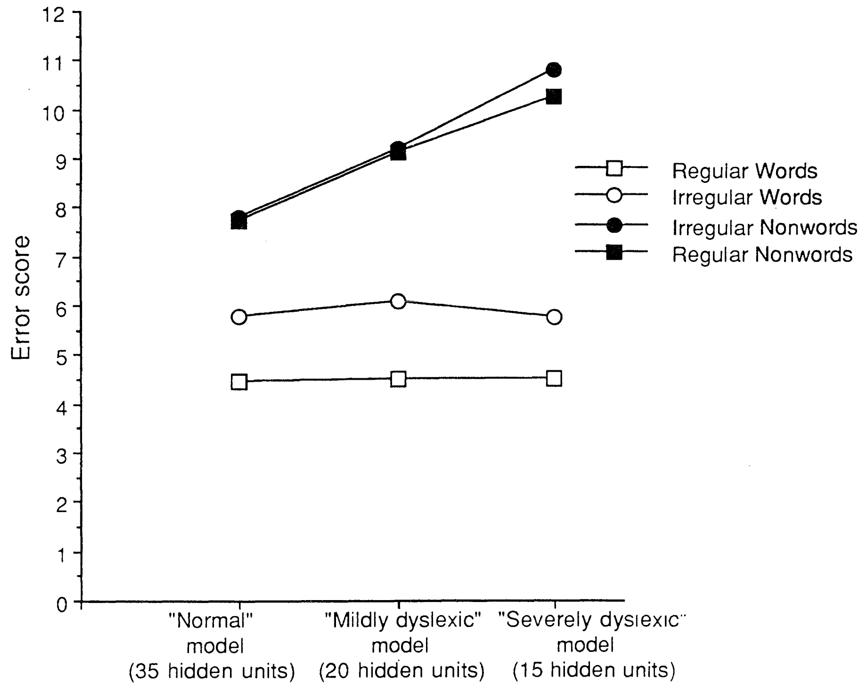

Fig. 1. Regularity effects and lexicality effects in a connectionist model of reading.

point was reached after 120 epochs of learning for the normal model, and after 345 and 1200 epochs of learning for the 'mildly dyslexic' and 'severely dyslexic' models respectively. The different models can therefore be considered to be matched on 'reading age' rather than 'chronological age' for the purpose of this comparison.

Figure 1 illustrates the critical result. It shows that the two 'dyslexic' models showed equal spelling-to-sound regularity effects to the 'non-dyslexic' model but greatly increased error scores to non-words (whether these non-words were derived from regular or irregular words). This is the pattern of results observed in experimental studies of dyslexia, which have shown that dyslexics have more difficulty than reading-age-matched non-dyslexic children in reading non-words, even though they show equivalent regularity effects. The model therefore behaves in a way which is paradoxical when interpreted in terms of the 'phonological deficit' hypothesis described earlier, for the non-word processing deficit has previously been taken to reflect 'deviant' processing in dyslexia, while the equivalent-sized regularity effects have been taken to reflect 'normal but delayed' processing in dyslexia.

The results must be treated with some caution owing to the restricted size of the model's vocabulary. Nevertheless, they demonstrate that the relative performance of the models with differing computational resources depends upon the performance metric that is adopted. Examining the difference between the models' error to regular and irregular members of the set to be learned does not show differences between systems with differing computational resources, while examining error to novel items does. It appears that non-word processing is a more sensitive measure of the generalisation capacity of a reading system than is the regularity effect. When computational resources are restricted in the model, it will use the resources that are available to it to learn the words in its vocabulary, and any residual computational capacity will be used for generalisation. We return to these issues in the general discussion.

A CONNECTIONIST APPROACH TO SPELLING

We now describe our own connectionist model of spelling development (Brown *et al.*, 1992), in an attempt to see if the connectionist approach can also account for some of the observed phenomena in this area. Spelling is a more difficult process than reading, computationally speaking, because the mapping from phonology to orthography in English is more irregular and ambiguous than the reverse process. Nevertheless, connectionist models have already exhibited some success in learning to spell (Olson and Caramazza, 1988).

How the Model Works

The model is a three-layer feedforward network similar to the reading model described above. The input and output layers both contain 50 units, and the hidden layer of the 'non-dyslexic' model version has 30 units. Fuller details can be found in Brown *et al.* (1992). Each input pattern represents the phonological form of a word, while the corresponding target output pattern represents the orthographic form. In the simulations reported here the network was trained to spell a set of 223 single-syllable words. The model learns the associations between pronunciations and spellings using backpropagation, as in the models of reading described above. This simply involves repeatedly adjusting the strengths of all the connections in the network, a little at a time, in such a way that the performance of the network gradually improves over time (Rumelhart *et al.*, 1986).

Vocabulary

Our main interest in the current modelling enterprise is with the model's ability to spell regular and irregular words. Irregular words have been defined as those which do not conform to the sound-to-spelling 'rules' of English. However, an alternative explanation for the apparent effects of *regularity* may be given in terms of sound-spelling *friends* and *enemies*. In the remainder of this paper we will continue to use the terms 'irregular' and 'regular', as this is most consistent with current usage, but 'irregular' words will be taken to be those with only enemies, while 'regular' words will be those with only friends.

It was necessary to devise a vocabulary that could be used both as input to the connectionist model and for use in the experiments on normal and dyslexic children described below. Nineteen pairs of words were produced and each pair contained a regular and matched irregular item. (We also examined a third class of word, but these results are not discussed here.) The words in each group were matched as closely as possible on word frequency, positional bigram frequency and word length. No word in the sample was homophonic with any other English word. The experimental set consisted of 19 such pairs. The network model learned a total of 223 words. The remaining words were included in order to give the regular and irregular words some friends and enemies respectively. For each regular word there were, on average, four words with similar orthography and phonology to act as friends, while each irregular word had an average of four words with similar phonology, but different orthography, to act as enemies.

A distributed encoding scheme similar to that employed by Rumelhart and McClelland (1986) and Seidenberg and McClelland (1989a) was used to create both the input and target patterns, in such a way that there was a tendency for phonologically similar words to have similar input patterns, and for orthographically similar words to have similar target patterns.

Assessment of Performance

The pattern error score (sum of the squares of the errors at the output units) of the actual output pattern with respect to the target output pattern was used as a relative measure of spelling accuracy, for comparing performance on different types of words. This measure is straightforward of interpretation: the higher the error score, the greater the difficulty the model has with learning that spelling and the less likely it would be that a correct spelling could be produced.

Developmental Dyslexia in the Model

In addition to examining the development of spelling in normal children, we wanted to assess the possibility that the spelling problems experienced by developmental dyslexics could be characterised in terms of reduced computational resources being devoted to the learning process, as we argued above in the case of reading. In our simulations of spelling we adopted a similar approach. The 'normal' model was given 30 hidden units, while a 'mildly dyslexic' model was provided with only 20 hidden units during the learning process, and a 'severely dyslexic' model was given only 15 hidden units.

RESULTS OF SIMULATIONS

Word Spelling in the Model

For all models, irregular words had the highest error score, and regular words had the lowest error score. Figure 2 shows the error score for regular and irregular words in the three different versions of the model. All show sound-to-spelling regularity effects, revealed in higher error scores for the irregular terms, but the 'dyslexic' versions of the model learn more slowly and never achieve the same level of accuracy as the non-dyslexic versions.

In order to assess non-word performance in the model we derived 'regular' and 'irregular' non-words based on the regular and irregular words. Each non-word was created by replacing the onset phoneme cluster in the phonological form of the word (e.g. */swp/* $\rightarrow$ */fwp/*). An input pattern based on this non-word could then be presented to the input layer, and the resulting pattern at the output compared with a pattern at the output compared with a pattern representing the target spelling of the non-word. In the case of non-words derived from irregular words, the target spelling was the regular form.

The three models, non-dyslexic (35 hidden units), mildly dyslexic (20 hidden units) and severely dyslexic (15 hidden units) were matched on their performance in spelling regular words. We examined error score for non-words and irregular words when the three different models showed an equal error score on the regular items. Thus this is a spelling-level match – the non-dyslexic model reached this level of performance after 130 epochs of learning, the mildly dyslexic model after 390 epochs, and the severely dyslexic model did not reach this level of performance until 1580 epochs of learning.

The results can be seen in Figure 3. It can be seen that the dyslexic models show almost equal error scores for the irregular items, but they show a dramatic rise in error scores for non-words derived from consistent

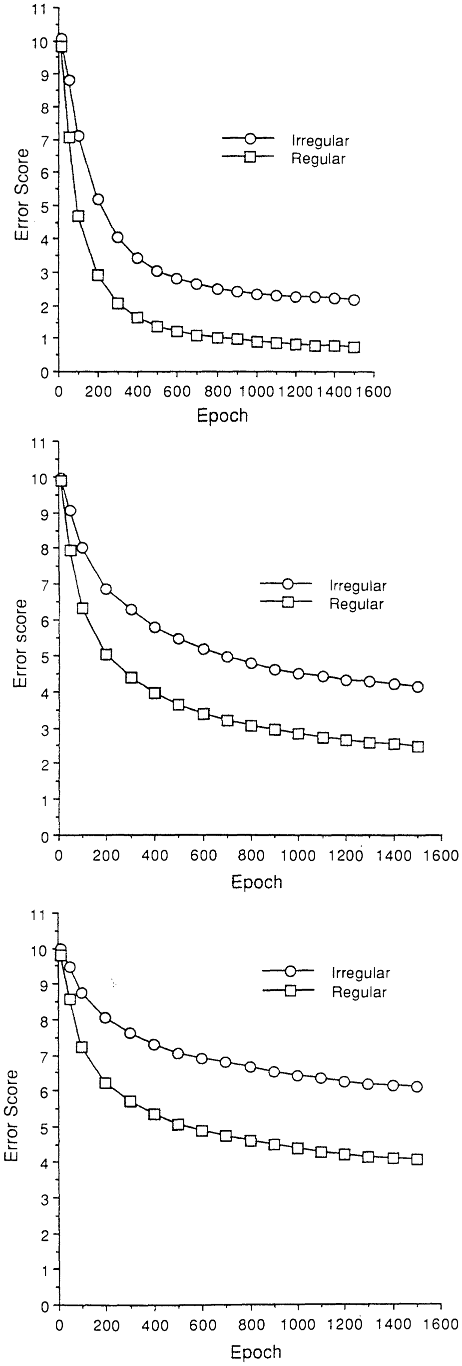

Fig. 2. The error scores to regular and irregular words and non-words for the dyslexic and non-dyslexic models of reading.

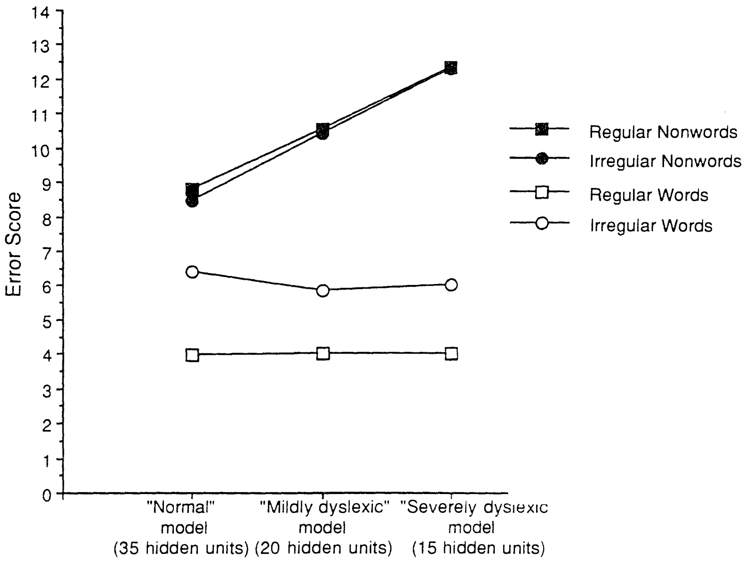

Fig. 3. The error scores to regular and irregular words and non-words for the dyslexic and non-dyslexic models of spelling.

words, and non-words derived from irregular words, as the number of hidden units is reduced.

How should we interpret these results? Non-word processing ability and regularity effects have been seen as two different indicators of the presence of alphabetic processing. These measures have led to contradictory theoretical interpretations in the literature. We suggest that this is because non-word processing ability provides a more sensitive measure of the generalisation capacity of a system. Thus experiments which look for non-word processing deficits in dyslexics compared with ability-matched controls are far more likely to find deficits than are studies which look for reduced sound-to-spelling regularity effects in dyslexic populations.

The results of the model which simulates dyslexia by using fewer hidden units are taken to suggest that the difference between normal and dyslexic spelling development can be well characterised in terms of the amount of computational resources devoted to the task. When insufficient resources are allocated to learning the relevant sound-to-spelling associations, the result is that a lower overall level of performance is achieved at any given stage in learning, but the ordering of the different word types in terms of accuracy is the same.

EXPERIMENTAL STUDIES

In this section we describe the results of an experiment that we carried out on normal adults and dyslexic children to test the predictions of the model.

Sound-to-Spelling Regularity in Dyslexia

The connectionist model of spelling that we described briefly above predicts that dyslexic children should show equivalent sound-to-spelling regularity effects when compared with non-dyslexic children reading at the same level. We tested this prediction by examining the spelling performance of 24 dyslexic and 24 matched non-dyslexic children. Twelve dyslexic children came from a Junior class, and 12 from a Senior class. All the dyslexic subjects had been formally diagnosed as having specific learning difficulties by an independent examiner and were attending a special school for dyslexic boys. Additional tests (using the British Ability Scales) showed that the Junior dyslexics had a reading age 30 months behind their chronological age, and the Senior dyslexics were 37 months delayed.

The stimulus materials used in the computational models were also those used in the experiment. For the spelling tests, each stimulus word was presented in a short sentence that used the word in a meaningful context but did not define its meaning. We also conducted a separate comprehension test, and analysed error rates only to words that were known to individual subjects.

Figure 4 presents the (untransformed) error proportions for the Junior and Senior dyslexics and controls.

In the comparison between dyslexic and control subjects there were main effects of both ability group and word type. There was no significance difference between control and dyslexic subjects (as expected, given that groups were matched on total spelling score) and, crucially, there were no significant interactions. Thus, we found that the dyslexics perform similarly to younger control subjects spelling at the same overall level. This is consistent with the behaviour of our 'developmentally dyslexic' model, which is provided with fewer hidden units over which to represent the statistical regularities inherent in the sound-to-spelling mapping problem.

The fact that our dyslexic and non-dyslexic children showed regularity effects of equal magnitude fails to support the hypothesis that the dyslexic children have not attained a stage of alphabetic processing, at least in spelling. Of course, these results do not exclude the possibility that the dyslexic subjects may differ in *reading* strategies: it is entirely possible that the dyslexics attain alphabetic spelling but not alphabetic reading, although the numerous studies (cited earlier) which have failed to find reduced spelling-to-sound regularity effects in dyslexic reading go against

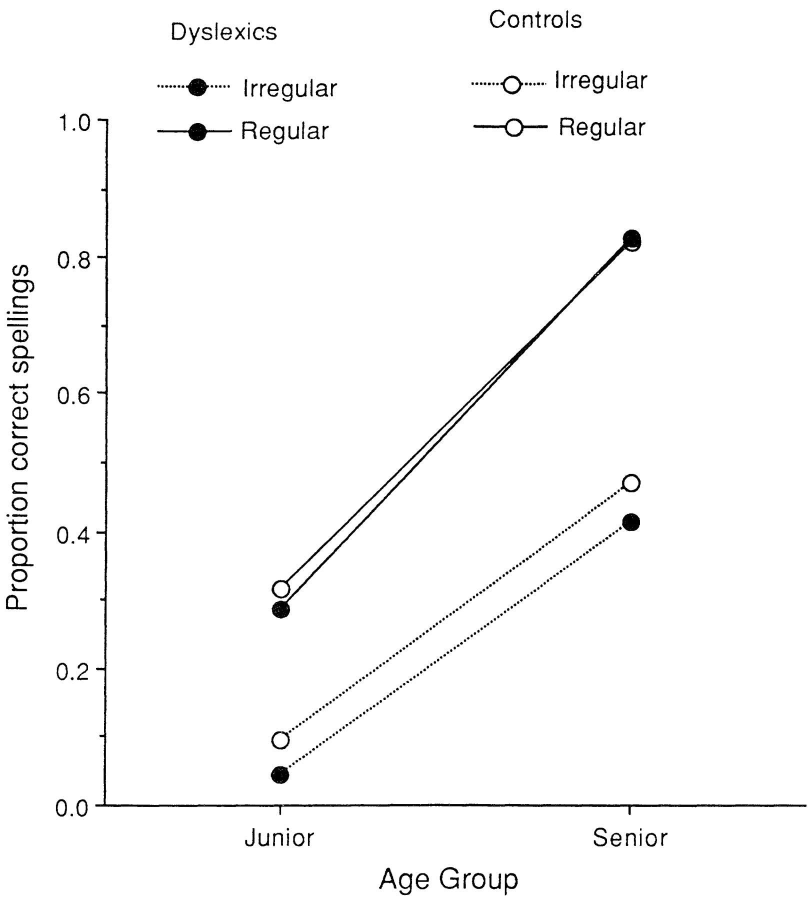

Fig. 4. Percentage correct responses for regular and irregular words for dyslexics and controls.

this conclusion. We should also note that our experiments militate against the conclusion that dyslexics show an *over*-reliance in phonological coding during spelling (Barron, 1980), for if this were so the dyslexics should show larger regularity effects, and in our experiment they did not do so.

We now examine the implications of the results for a number of the theoretical issues that were raised at the beginning of this chapter.

DISCUSSION

Delay or Deviance?

We now assess the extent to which connectionist models can illuminate some critical theoretical issues in the study of developmental dyslexia. As we described in the introduction, one important question has been whether the processing of dyslexic children is 'delayed' or 'deviant'. The most common version of the 'deviance' hypothesis is that dyslexics do not progress to an 'alphabetic' stage of reading and spelling in which they make fluent use of sound-to-spelling or spelling-to-sound rules. This does not preclude the possibility that they may, after the point of developmental arrest, go on to develop compensatory strategies of some kind (perhaps as a result of instruction, or perhaps involving greater development of a visual/lexical non-alphabetic spelling routine). The 'delay' hypothesis, in contrast, implies that dyslexic children progress through the same stages as non-dyslexic children, but at a slower rate.

In the study of both reading and spelling, two different experimental strategies have been used to determine whether or not dyslexic children who are processing at the same overall level as control groups are processing in a qualitatively different way as predicted by the deviance model. One strategy looks for the reduced regularity effects that should be apparent in dyslexic children if they are making no use, or less efficient use, of sound-to-spelling or spelling-to-sound rules. The second strategy looks for the deficit in non-word processing that would be expected in dyslexic populations under the same hypothesis. These different experimental strategies have produced conflicting results, for in the case of both reading and spelling most (although not all) recent studies have found no reduction in regularity effects in dyslexic populations when matched with appropriate control groups. Most of these studies have looked at reading (see Brown and Watson, 1991, for a review) and our own experiment described above has found the same pattern for spelling. These results have been interpreted as evidence against a selective deficit in alphabetic processing in dyslexia. However, a much higher proportion of studies have been successful in finding selective non-word reading and spelling deficits in dyslexia, and this is consistent with a wide range of evidence supporting the presence of a general phonological processing deficit in dyslexia. These results do point to qualitatively different processing in dyslexia, supporting a 'deviance' model. We have argued that connectionist models of reading and spelling reproduce this apparently paradoxical pattern of effects, and we have suggested that this is because non-word processing is a more sensitive measures of the generalisation performance of a system than the magnitude of regularity effects.

Dual-Route and 'Stage' Models

In the case of reading, connectionist models have frequently been interpreted as evidence against 'dual route' models of reading, in which there are both lexical and non-lexical routines for synthesising the pronunciation of words. The question arises, therefore, of whether connectionist models of spelling, of the type we have described above, can be seen as potential replacements for traditional rule-based information processing models (mainly dual-route models, in this case). To do this, we now assess the ability of the model to account for the evidence hitherto interpreted as arguing for dual-route models.

Ability to Spell Irregular Words

The fact that people can correctly spell irregular items such as SOAP has been taken as evidence that a single-route model cannot work. However, our connectionist model, even though it does not contain two distinct components, can nevertheless learn to spell words with irregular spellings. Further evidence is provided by another connectionist model of spelling development, that of Olson and Caramazza (1988) which also learns to spell both regular and irregular words.

Developmental Evidence

The nature of children's spelling errors changes over time. According to the standard 'stage' accounts, children go through an initial logographic stage in which they omit letters, and may then spell syllables by the letter whose name is that syllable. At this stage they do not show sound-to-spelling effects. Such regularity effects will emerge in the next stage of spelling, however, as the child begins to grasp the alphabetic principle. Children may incorrectly spell words that they previously spelled correctly as they make the transition between different stages of development. Regularity effects will finally become smaller, and perhaps disappear altogether, as children cease to rely solely on sound-to-spelling translation and acquire knowledge of exceptional spellings.

We have not conducted a detailed analysis of the nature of the errors made by our model, for several reasons. Firstly, the limited vocabulary of the model precludes the meaningfulness of such analysis. Secondly, the nature of the input/output representations that a model uses will be crucial to the particular errors that are produced, and we claim no particular psychological plausibility for the nature of the representations we have chosen. Indeed, it is clear that a complete model would need to use some other representational scheme. However, we have argued (as have Seidenberg and McClelland, 1989a) that the precise nature of the input/output representations is not crucial provided they embody enough of the structure of the input and output domains to enable the model to capture some of the co-occurrence relationships between the two.

Evidence from Acquired Dysgraphia

One traditional source of evidence for the existence of two separate spelling routines has been the pattern of impairments suffered by brain-injured patients. Some patients ('phonological dysgraphics') selectively lose the ability to spell non-words while the ability to spell real words (whether regular or irregular) is relatively well preserved (e.g. Shallice, 1981). In terms of dual-route models of spelling, this is taken as evidence for loss of the non-lexical sound-to-spelling translation pathway. So-called 'deep dysgraphics' exhibit similar problems but also produce semantically related errors. The complementary syndrome, variously known as 'surface dysgraphia' (Ellis, 1984), 'lexical dysgraphia' (Beauvois and Dérousné, 1981) or 'phonological spelling' (Hatfield and Patterson, 1983), involves a relative preservation of the sound-to-spelling translation routine, allowing spelling of regular words and non-words, along with impairment of the lexical spelling routine. These patients therefore have particular difficulty in spelling words with exceptional sound-spelling correspondences. The picture is of course more complex than the simple one presented above (see Ellis and Young, 1988, for a review), and patients vary in the extent of dissociation which they exhibit.

Elsewhere (Loosemore *et al.*, 1991) we have shown that 'lesioning' the model, after it has learned, can lead to a selective deficit in spelling irregular words similar to that shown by surface dysgraphics (cf. also Olson and Caramazza, 1988). Patterson *et al.* (1989) have provided a similar demonstration in the case of the connectionist model of reading described earlier. However, it remains to be shown that a unitary connectionist model can handle the complementary pattern of impairment as observed in phonological dysgraphia.

Development of Phonemic Awareness

In this section we discuss ways in which the connectionist approach could improve our understanding of the development of phonemic awareness. Longitudinal studies (e.g. Cataldo and Ellis, 1988; Mommers, 1987; Shanahan and Lomax, 1986) have demonstrated the importance of spelling in the development of levels of phonemic awareness. One of the key findings of the past decade is that phonemic awareness, first implicit and then explicit, is an excellent predictor of subsequent reading ability. The large literature cannot be more than touched on here, but for present purposes we simply offer some suggestions as to how a connectionist approach might enable us to understand how a computational system could develop phonemic awareness partly as a process of learning to spell.

It is well known that simple connectionist learning algorithms can lead to the establishment of 'interesting' and economical representations over layers of hidden units. This applies particularly to sequential networks, which can deal with temporal information flow (Elman, 1988). Indeed, Hanson and Burr (1990) have argued that this integration of 'learning' and 'representation' is the major contribution of connectionism. It may be that the development of such representations is related to the ability of the system to exhibit implicit 'phonemic awareness'. These hidden-unit representations can then be recruited to enable spelling development, which will in turn influence the hidden-unit representations and explicit phonemic awareness.

The nature of the representations that are formed will depend upon the task requirements. We argue that spelling imposes different requirements to the prior development of spoken language. More specifically, the temporal segmentation that is required for the former is more specific, or temporally fine-grained. We are currently exploring the possibility that the provision of alphabetic knowledge (in the form of a set of output units representing letters), and the additional requirement to learn sound-spelling mappings (over and above the mappings needed to learn to produce a sequence of phonetic features) can force the development of the more specific phonemic representations over hidden units. The hidden unit representations, which can come to encode temporal features, are then taken as the input to letter-representing output units, and the system is required to learn (using the standard propagation algorithm) to produce the correct letter sequences as well as the correct sequences of articulatory features. Thus the ability to learn sound-letter mappings will depend on the specificity of the hidden-unit representations available at any given point in time, and the need to develop spelling ability can in turn motivate the development of 'sharper' hidden representations which are comparable to the development of explicit phonemic awareness.

CONCLUSION

In this chapter we have attempted to show how the use of computational modelling techniques within a connectionist framework can increase our understanding of the development of reading and spelling in normal and developmentally dyslexic children.

The work of Seidenberg and McClelland, and our own connectionist model of spelling reported here and elsewhere, have, we argue, demonstrated a number of points. First, connectionist models can learn to read and spell both regular and irregular words. During learning, the relative difficulty that the models experience with the different word types closely mirrors the level of difficulty experienced on the same words by children. We take this to show that the process of learning to read and spell can usefully be viewed as a statistical one, involving the gradual mastery of associations between patterns in one domain and patterns in another. Further evidence for this conclusion comes from studies of 'lesioned' networks – removing computational processing capacity from a system which has already learned a mapping leads to deficits which are qualitatively similar to those experienced by certain brain-injured patients.

Furthermore, we have shown that in conducting experiments looking at sound-to-spelling 'regularity' effects it is important to control for the number of 'friends' a words has as well as its number of 'enemies'. Previous experimental studies of spelling regularity have generally confounded these two factors.

With regard to the cognitive processing deficit in developmental dyslexia, we have argued that much of the pattern of difficulty experienced by dyslexics in spelling can be explained in terms of the dyslexic children allocating fewer processing resources to the learning process. Furthermore, the model offers an explanation of a paradoxical finding in the literature – the observation that dyslexics, when matched with appropriate controls, seem more likely to exhibit a selective deficit in non-word processing than a reduced regularity effect, even though both of these are predicted by the hypothesis that dyslexics suffer a selective difficulty in alphabetic processing.

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REFERENCES

Baddeley, A. D., Logie, R. H. and Ellis, N. C.: 1988, 'Characteristic of developmental dyslexia', *Cognition* **29**, 197–228.

Barron, R. W.: 1980, 'Visual and phonological strategies in reading and spelling', in U. Frith (ed.), *Cognitive Processes in Spelling*, Academic Press, London, pp. 195–213.

Barry, C. and Seymour, P. H. K.: 1988, 'Lexical priming and sound-to-spelling contingency effects in nonword spelling', *Quarterly Journal of Experimental Psychology* **40(A)**, 5–40.

Beech, J. R. and Harding, L. M.: 1984, 'Phonemic processing and the poor reader from a developmental lag viewpoint', *Reading Research Quarterly* **19**, 357–366. Beauvois, M.-F. and Dérousné, J.: 1981, 'Lexical or orthographic dysgraphia', *Brain* **104**, 21–50.

Besner, D., Twilley, L., McCann, R. S. and Seergobin, K.: 1990, 'On the association between connectionism and data: Are a few words necessary?', *Psychological Review* **97**, 432–446.

Bradley, L. and Bryant, P.: 1981, 'Visual memory and phonological skills in reading and spelling backwardness', *Psychological Research* **43**, 193–199.

Brown, G. D. A.: 1987, 'Resolving inconsistency: A computational model of word naming', *Journal of Memory and Language* **23**, 1–23.

Brown, G. D. A., Loosemore, R. and Watson, F. L.: 1992, 'Normal and dyslexic spelling: A connectionist approach', submitted.

Brown, G. D. A. and Watson, F. L.: 1991, 'Reading in developmental dyslexia: A connectionist approach', in M. Snowling and M. Thomson (eds.), *Dyslexia: Integrating Theory and Practice*, Whurr Publishers, London, pp. 165–182.

Brown, G. D. A., Watson, F. L. and Loosemore, R.: 1993, 'Regularity effects in dyslexia: A review, an experiment, and a model', submitted.

Campbell, R.: 1985, 'When children write non-words to dictation', *Journal of Experimental Child Psychology* **40**, 133–151.

Caramazza, A., Miceli, G., Villa, G. and Romani, C.: 1987, 'The role of the graphemic buffer in spelling: Evidence from a case of acquired dysgraphia', *Cognition* **26**, 59–85.

Cataldo, S. and Ellis, N. C.: 1988, 'Interactions in the development of spelling, reading and phonological skills', *Journal of Research in Reading* **11**, 86–109.

Ellis, A. W.: 1984, *Reading, Writing and Dyslexia*, Lawrence Erlbaum, London.

Ellis, A. W. and Young, A. W.: 1988, *Human Cognitive Neuropsychology*, Lawrence Erlbaum, London.

Elman, J. L.: 1988, *Finding Structure in Time*, CRL Technical Report 8801, University of California, San Diego.

Frith, U.: 1980, 'Unexpected spelling problems', in U. Frith (ed.), *Cognitive Processes in Spelling*, Academic Press, London, pp. 495–515.

Frith, U.: 1985, 'Beneath the surface of developmental dyslexia', in K. E. Patterson, J. C. Marshall and M. Coltheart (eds.), *Surface Dyslexia*, Lawrence Erlbaum, Hillsdale, NJ, pp. 301–330.

Frith, U. and Snowling, M.: 1983, 'Reading for meaning and reading for sound in autistic and dyslexic children', *British Journal and Developmental Psychology* **1**, 329–342.

Hanson, S. J. and Burr, D. J.: 1990, 'What connectionist models learn: Learning and representation in connectionist networks', *Behavioral and Brain Sciences* **13**, 471–518.

Hatfield, F. M. and Patterson, K. E.: 1983, 'Phonological spelling', *Quarterly Journal of Experimental Psychology* **35(A)**, 451–468.

Jorm, A. F.: 1981, 'Children with reading and spelling retardation: Functioning of the whole-word and correspondence-rule mechanisms', *Journal of Child Psychology and Psychiatry* **22**, 171–178.

Loosemore, R. L., Brown, G. D. A. and Watson, F. L.: 1991, 'A connectionist model of spelling development and developmental and acquired dyslexia', *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society*, Lawrence Erlbaum, Hillsdale, NJ.

McClelland, J. L. and Rumelhart, D. E.: 1981, 'An interactive model of context effects in perception', *Psychological Review* **88**, 375–407.

Mommers, M. J. C.: 1987, 'An investigation into the relationship between word recognition, reading comprehension and spelling skills in the first two years of primary school', *Journal of Reading Research* **10**, 122–143.

Olson, A. and Caramazza, A.: 1988, 'Lesioning a connectionist model of spelling', talk given at Venice III: *Cognitive Neuropsychology and Connectionism*, October 3–7, 1988, Venice, Italy.

Patterson, K. E., Seidenberg, M. S. and McClelland, J. L.: 1989, 'Connections and disconnections: Acquired dyslexia in a computational model of reading processes', in R. G. M. Morris (ed.), *Parallel Distributed Processing: Implications for Psychology and Neurobiology*, Oxford University Press, Oxford, pp. 131–181.

Prince, A. and Pinker, S.: 1988, 'Wickelphone ambiguity', *Cognition* **30**, 189–190.

Rack, J. P., Snowling, M. J. and Olson, R. K.: 1992, 'The nonword reading deficit in developmental dyslexia: A review', *Reading Research Quarterly* **27**, 29–51.

Rumelhart, D. E. and McClelland, J. L.: 1986, 'On learning the past tenses of English verbs', in J. L. McClelland, D. E. Rumelhart and the PDP Research Group (eds.), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 2: Psychological and Biological Models*, MIT Press/Bradford Books, Cambridge, MA, pp. 216–271.

Rumelhart, D. E., Hinton, G. E. and Williams, R. J.: 1986, 'Learning internal representations by error propagation', in D. E. Rumelhart, J. L. McClelland and the PDP Research Group (eds.), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition. Volume 1: Foundations*, MIT Press/Bradford Books, Cambridge, MA, pp. 318–362.

Seidenberg, M. S.: 1989, 'Visual word recognition and pronunciation: A computational model and its implications', in W. Marslen-Wilson (ed.), *Lexical Representation and Process*, MIT Press/Bradford Books, Cambridge, MA, pp. 25–74.

Seidenberg, M. S., Bruck, M., Fornarolo, G. and Backman, J.: 1985, 'Word recognition processes of poor and disabled readers: Do they necessarily differ?', *Applied Psycholinguistics* **6**, 161–180.

Seidenberg, M. S. and McClelland, J. L.: 1989a, 'A distributed, developmental model of word recognition and naming', *Psychological Review* **96**, 523–568.

Seidenberg, M. S. and McClelland, J. L.: 1989b, 'Visual word recognition and pronunciation: A computational model of acquired skilled performance and dyslexia', in A. Galaburda (ed.), *From Reading to Neurons*, MIT Press/Bradford Books, Cambridge, MA, pp. 255–303.

Seidenberg, M. S., Waters, G. S., Barnes, M. A. and Tanenhaus, M. K.: 1984, 'When does irregular spelling or pronunciation influence word recognition?', *Journal of Verbal Learning and Verbal Behavior* **23**, 383–404.

Seymour, P. H. K. and Porpodas, C.: 1980, 'Lexical and non-lexical processing of spelling in dyslexia', in U. Frith (ed.), *Cognitive Processes in Spelling*, Academic Press, London, pp. 443–472.

Shallice, T.: 1981, 'Phonological agraphia and the lexical route in writing', *Brain* **104**, 413–429.

Shanahan, T. and Lomax, R. G.: 1986, 'An analysis and comparison of theoretical models of the reading-writing relationship', *Journal of Educational Psychology* **78**, 116–123.

Snowling, M. J.: 1981, 'Phonemic deficits in developmental dyslexia', *Psychological Research* **43**, 219–234.

Snowling, M. J., Goulandris, N., Bowlby, M. and Howell, P.: 1986, 'Segmentation and speech perception in relation to reading skill: A developmental analysis', *Cognitive Neuropsychology* **3**, 309–339.

Szeszulski, P. A. and Manis, F. R.: 1987, 'A comparison of word recognition processes in dyslexic and normal readers at two reading-age levels', *Journal of Experimental Child Psychology* **44**, 364–376.

Treiman, R. and Hirsh-Pasek, K.: 1985, 'Are there qualitative differences in reading behaviour between dyslexic and normal readers?', *Memory & Cognition* **13**, 357–364.

Watson, F. L. and Brown, G. D. A.: 1992, 'Single word reading in college dyslexics', *Applied Cognitive Psychology* **6**, 263–272.

ROBERT J. JARVELLA

MORPHOLOGY IN SKILLED WORD RECOGNITION

ABSTRACT. This paper addresses the question of how skilled readers may use sub-wordform-based strategies to (a) identify lexical entries corresponding to single printed words, and (b) perceive printed words while at the same time integrating grammatical information in a sentence. Results from research in Italian, Dutch, and Swedish are first reviewed which support readers' use of morphologically-defined letter strings called 'handles', to identify words' lexical bases, or stems. Work in the same three languages is then presented which suggests involuntary processing of lexical bases and affixes during the reading of ill-formed language sequences. Finally, it is shown that, in more normal reading, rather than words' lexical bases, it is the grammatical features of words which can be anticipated from context, also in near-real time. Initially independent processing of a wordform's handle and grammatical ending may characterize skilled reading in the languages considered.

INTRODUCTION

Recent experimental research on printed word recognition in European languages has begun to point to rather widespread use of morphology during skilled reading. In the present paper, I will review some research in this area. Except largely in passing, I will not deal with the reading of English, or with problems that children experience in learning to read English. Let me begin by motivating a cross-linguistic and more skill-oriented approach.

The work reported in this volume is largely about deviations from normal reading. If one sets out to describe reading with the aim of explaining reading disorders, one needs to make some assumptions about (have a general theory of) what the reading process is like normally. Now, the reading process may vary quite a lot. Among other things, it will tend to vary with the language used, with the system used to represent it in writing, and with the kind of reading which is performed in the language. To the extent that there are quite general principles underlying skilled reading, these will always be instantiated in a language-specific way, i.e., depend on specific properties of the language at hand.

In this kind of perspective, to base one's starting assumptions about the reading process on research done in a single language and one culture is unrealistic. This is so even if the existing body of findings from the language at hand is quite extensive, as it is for reading done in English. Conclusions about reading done in any given language may not be easily

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generalizable to reading done in other languages, and thus assumptions about reading in general which are based on English data may be false or misleading. The fact that so much research concerned with word recognition and reading comes from studies done in English may tend to bias our understanding of reading as a linguistic behavior.

It is perhaps more obvious that better understanding of skilled reading is desirable for similar reasons. A developmental perspective is not inappropriate for approaching the problems which children may face in learning to read. The reading skills which are acquired in childhood, however, usually are only a subset of those which define adult literacy. Unless one wishes to consider early development and that alone, it would be wise to take account of the growth of skills which come (or not) from prolonged experience with written language.

In the present paper, I will make a case for a significant role of morphology in skilled reading in several European languages. Recent work concerned with how, when reading, we deal with words' inner grammatical form has been in some disagreement about the role played by morphology. The disagreement ranges over both the use of morphology in the lexical-lookup process in word recognition, and use of grammatical information encodable from words in parsing sentences. Part of the disagreement may be attributable to a failure to take into account variation between languages.

Though the belief is not shared by all who have studied English, the internal structure of words is widely viewed there as playing little role in processing done at either a lexical or higher grammatical level (see e.g., Butterworth, 1983; Becker and Freeman, 1979; Seidenberg and McClelland, 1989). Work done in this one language may tend to support a non-morphological view. But the language on which it is based is hardly very rich in the sense intended. Most inflection in English, for example, is managed by just three suffixes (-s, -ed, and -ing), which are all used in some nominal, verbal, and adjectival forms, and thus underspecify a wordform's grammatical class.

If one considers related languages which have morphologies somewhat more elaborate than in English, the conclusion one will draw about the role in reading of words' internal structure may be different. In Romance languages, and in Scandinavian and other Germanic languages, processing of morphological structure may help enable efficient word recognition and parsing (c.f. Caramazza *et al.*, 1988; Jarvella *et al.*, 1987). In more agglutinative languages such as Turkish and Finnish, which have far richer morphologies, the role of words' internal structure in reading may necessarily be both extensive and elaborate. Here, I will take up data from languages less extreme than English and Turkish, which nevertheless tend to illustrate the processing of word-internal structure in reading.

PERCEPTION OF ISOLATED WORDS

In 1974, Eriksen and Eriksen published a paper on the latency to name English four-letter words which introduced a new method. The method was to display the letters in a wordform partly asynchronously. At stimulus onset, some of the word's letters were made visible (e.g., _NOW from SNOW), and after a fraction of a second, the letters which had been delayed were also made visible (i.e., the S in SNOW was added to _NOW at the appropriate visual location). Over the range of eight stimulus-onset asynchronies (SOAs) studied from 10 to 500 milliseconds (msec), Eriksen and Eriksen found that presenting just the end of a printed word was initially of little help in naming it. Unless the wordform's *first letter* was displayed, the word recognition process seemed unable to respond.

More recent word done in English to distinguish how word-initial letter information might serve lexical access is reported by Lima and Pollatsek (1983) and by Taft (1987). Taft (1987, Exp. 1), using a 200 msec SOA, found less priming of word recognition in a lexical decision task when the initial sequence shown from a word was the form's first (phonological) syllable than when it was the word's 'basic orthographic syllable structure' (BOSS), a morphographic unit which he takes (Taft, 1979) to map onto a word's root.[1] On the other hand, Lima and Pollatsek (1983, Exp. 3), using a 90 msec SOA, found priming by BOSS sequences in lexical decision only when a word's BOSS coincided with the form's root.

In 1983, with Remo Job, Rob Schreuder, and Görel Sandström I began doing naming and lexical decision experiments using SOAs in Italian and Dutch. The subjects we studied were mainly students at universities, who are relative good readers. The SOAs which we employed were very small (ranging from 30 to 60 msec), and hardly noticeable to the uninformed subject's eye (see Jarvella, 1990; Jarvella *et al.*, 1987). But they were large enough to ask the following question: Is it likely that a printed word is recognized from its letter pattern in one step, or more in a succession of steps? If a word is recognized in a single step, briefly withholding letters from the pattern should delay its recognition. If a word is recognized in more than one step, withholding non-critical letters from the pattern at first may leave time needed to recognize the form unaffected.

In our studies, the substrings of a word's letters which were initially presented and withheld from a reader's view were defined morphologically. In experiments in both languages which we began to study, we found that not presenting certain *word-final* letters from words at stimulus onset seemed to have little retarding effect on readers' response latencies, when compared to a full-form (all-letters-at-once) control condition. On the other hand, when *word-initial* letters were withheld at first, there was generally

TABLE 1

Mean latency (msec) measured from stimulus onset needed to name Italian and Dutch words with all letters shown at once, and with some of their letters delayed.

Language studied	SOA used	Part-of-word initially displayed		
		ALL	BEG	Control
Italian	40	693	706	731
Dutch	60	597	606	638[a]

[a] Estimated for random letter set matched with BEG in size.

Source: Jarvella *et al.* (1987) and Sandström *et al.* (1990).

a significant delay in the time needed to make a lexical decision about a form, or say a word aloud.

In Table 1, I summarize some Italian and Dutch naming data which we gathered which seem to show a kind of initial *functional equivalence* between a beginning-of-word substring of letters (BEG) and a word's full form (ALL). The data shown in the table come from five experiments, three in Dutch (Sandström *et al.*, 1990) and two in Italian (Jarvella *et al.*, 1987). The SOAs used were 60 and 40 msec respectively. For the words studied here, a word-initial letter pattern shown for the first few hundredths of a second permitted adult readers to name the word about as fast on average as its full form.

We know further from studies of Italian in which we employed a lexical decision task (Jarvella and Job, 1985, 1988) that the kind of functional equivalence shown in Table 1 between a word-initial string and a full form shown can also be obtained in that setting. (Non-words used as filler items in these latter studies were phonotactically well formed and constructed by changing one letter in a word's lexical base or affix.) Thus, the effect does not seem to be specific to the latency to name a printed word.

For end-of-word substrings and other conditions which we included in Dutch and Italian as controls, moreover, reliable results were also found. Consistent with Eriksen and Eriksen's original finding for English, when word-initial letters were delayed, the last part of a word tended to be of little or no help. In some cases (see Jarvella *et al.*, 1987), showing only word-final letters at first seemed destructive to the recognition process.

For both Italian and Dutch, our experimentation revealed a key needed to obtain the pattern of essentially equal reaction times shown for the BEG and ALL conditions in Table 1. A word-initial string seen from a wordform needed to fulfil two conditions: (1) a particular part of the word (in Dutch, the word's (largest) stem, in Italian the word's lexical root) needed to be present in the string; (b) a particular part of the word (in Dutch, the word's lexical root, in Italian its stem) needed to be possible to individuate (determine) from the string. The fact that the two conditions are specified at opposite levels in the two languages may be a reflection of structural differences between them.

For an Italian word such as 'parlavamo' ('talk'-imperfect-1pl), the minimum beginning-of-word substring that would be needed to produce an effect of functional equivalence with the full form would be 'parlav', which displays the root 'parl-' and in principle allows the form to be discriminated as coming from the verb 'parlare' (and not, e.g., from the noun 'parlamento' having the same root). For a Dutch word such as 'activeren' ('activate'-present pl/infinitive), the minimal BEG substring which would be needed to produce the effect of functional equivalence with the full form would be 'activer', which is the word's stem and sufficient in principle to determine its root. In each language, in cases that we tested in which word-initial substrings shown met only one of the two conditions mentioned (or neither of them), a significant delay in naming words generally resulted. In Dutch, a further condition needed for obtaining functional equivalence between a substring of a word's letters and its full form was that the form *not* begin with a lexical prefix (see Sandström *et al.*, 1990).

What is the significance of such results? I tend to interpret the initial functional equivalence suggested by our data as indicating that, for skilled readers, there are perceptual *handles* to printed word forms, i.e., letter sequences which are morphologically based and, in word recognition, identify, or point to, addresses for the lexical representations of words. When a wordform is viewed, a reader may first detect such a handle, and then identify a path to an internal lexical representation. In both Italian and Dutch, the graphic information defining a handle would sometimes be insufficient to discriminate a target word from some related wordforms. Rather, a family of wordforms would be identified, of which the target was one member.

In Italian, the forms reached via a handle for an inflected verb form would be inflected forms of that particular verb lexeme. Excluding constructions which contain non-finite forms, that number could range up to about 40. Similarly, the forms which could be reached in Italian via the handle of a noun or adjective might include the word's singular and plural, and masculine and feminine forms (if they are different), plus perhaps some augmentative variants (e.g., diminutives). For each of these major word classes, the total number of wordforms corresponding to a given handle would tend to be larger than unity. If such a route to printed word recognition was used, it is evident that an ulterior step would be needed to determine which form of a noun, verb, or adjective was involved.

There is some evidence from our research about such a second stage in Italian printed word recognition. Recognition latencies (again from both naming and lexical decision tasks) increase linearly with the length (and presumably complexity) of an inflection in Italian. On independent samples of nearly 500 words each, it was found in work done at the University of Padova that inflectional length accounts for about half of the variance in lexical decision latencies. To describe these phenomena, the model with which Remo Job and I have been working is a serial model.

We suppose that a reader first detects a word's orthographic handle, a pointer to a set of related forms in the mental lexicon; and secondly, that a particular form of the word addressed by the pointer is identified from among the members of the set. The latter step might be taken on the basis of further comparison with the stimulus, or in context, also on the basis of local grammatical constraints (see below).

Superficially, our model of recognition of single printed Italian words resembles a model described by Forster (1976) for English. But, unlike Forster's 'search' model, it is motivated morphologically, and works more deterministically. The links which we suppose connect Italian spelling with words' lexical representations derive from wordforms' internal structure, and are pathways leading to items which share a lexical base.

In practice, it is the stems of words which seem to be individuated by morphological handles in Italian. Inflectional suffixes may be processed there in a qualitatively different way than words' stems. English, like Italian, is a largely suffixing language. However, to identify a word's stem and grammatical class unambiguously, a comparable handle in English would tend to include all the letters in a wordform (often plus a following space marking a word boundary). Thus, the kind of process suggested above for Italian could operate vacuously in English. A short SOA method would not be expected, however, to uncover initial functional equivalence between BEG substrings and full forms.

The involvement of morphology in the word-recognition process in languages other than English, as revealed by experiments using the short SOA method, may also reflect quite advanced word-reading skills. Let me give some reason for this conjecture. The evidence I will cite comes from lexical decision experiments conducted in a third language we have studied, Swedish.

In studies done in Swedish using subjects at a comparable educational level to the studies reviewed above and SOAs of 40–60 msec, we have found a similar tendency for initial functional equivalence between BEG substrings from words and full forms, but only for certain words and certain readers (Jarvella, 1990; Jarvella *et al.*, 1990). There, the effect has been found for Scandinavian words which have high frequency roots (such as 'dörr/en', 'door'-sg definite; 'tänk/te', 'think'-past), and where the root is also a word's full lexical base (its largest stem). For such items, the initial presence vs. absence of a final inflection in the visual stimulus does not seem to affect lexical decision latencies, i.e., responses are as fast when only a word's stem is shown at first as when its letter pattern is displayed immediately and all at once.

Secondly, there are readers for whom this kind of effect has been found more generally. These subjects tend to be ones who are relatively fast as classifying letter strings in this kind of experimental context. (Again, non-word filler items studied were phonotactically regular and derived from real words.) For readers with faster than average decision time, the initial functional equivalence between a word-initial substring of letters and a full form extended to words which have less frequent roots and stems. Both the frequency- and subject-speed-related interactions we have found with BEG vs. ALL stimuli in Swedish may derive from extended familiarity with printed language.

DETECTION OF MORPHOLOGICAL REGULARITY

I want now to take up some work which suggests that, for the same three languages – Italian, Swedish, and Dutch – morphological structure may often be assigned involuntarily in the reading of ill-formed language sequences. Such morphological processing would be especially noteworthy if the mechanisms which are used for reading in general are also engaged in reading partly grammatical input. A priori, there is no reason to doubt that this would be the case.

A number of lexical decision studies (e.g., Henderson *et al.*, 1984; Laudanna and Burani, 1985) have shown that a letter string presented in a lexical decision task takes relatively long to recognize as *not* being a word, if it contains a pseudolexical base (e.g., 'smick' in English) concatenated with a real affix (e.g., '-ed' in English). This kind of morphological reflex would be difficult to explain if affixes had no internal sublexical representations, or if they were inseparable from actually occurring lexical bases. The phenomenon, moreover, does not seem to be restricted to the detection of affixes.

In several investigations (Caramazza *et al.*, 1988; Jarvella and Wennstedt, 1993), it has namely been found that a lengthening of lexical decision times will also occur if a non-word contains a real base (root or stem) but non-affix, and that when a non-word is made up of both a real base and a real affix in a non-occurring combination, a still greater lengthening of decision time results. In Table 2, some Italian and Swedish data are presented which illustrate these phenomena.

TABLE 2

Mean lexical decision latency (msec) for Italian and Swedish non-words composed of a novel or real lexical base, and a non-existent or real suffix.

Language	Non-lexical base with		Lexical base with	
	Non-suffix	Suffix	Non-suffix	Suffix
Italian	760	809	781	875
Swedish	994	1134	1093	1357

Source: Caramazza *et al.* (1988) and Jarvella and Wennstedt (1993).

For the Italian data shown in Table 2 (Caramazza *et al.*, 1988, Exp. 1), a non-word's real lexical base was a verb stem and its suffix was a verbal inflection. For the Swedish data shown (Jarvella and Wennstedt, 1993, Exp. 1), a non-word's real lexical base was a root and its suffix was a derivational one. If one takes the lefthand column of data in Table 2 as a baseline, where a stimulus item contained neither a real lexical base nor real affix (i.e., no morphologically-defined substring), it can be seen from the two middle columns that the presence of one morphemic subpart (of either kind) led to a slowdown in latency to reject the item. The presence of two such parts in a non-occurring combination (in the righthand column), however, led to a still greater slowdown in decision time. This suggests that not only are there separate morphological representations for lexical bases and affixes, but that in the lexical base+affix condition studied, perhaps something further happens. An additional lexical comparison (cf., Caramazza *et al.*, 1988; Taft and Forster, 1975) may have served there to determine that the combination was not an occurring one. Note also that the same kind of effect is observed on different linguistic levels, in inflection (in Italian), and in derivation (in Swedish).

Now, a question of some interest is whether the kind of effects shown in Table 2 are typical or atypical of the recognition of print in the languages that were studied. Is the morphological processing they reveal restricted to novel (and here deviant) cases, or does it play a similar role in the reading of other, well-formed sequences?

Caramazza *et al.* (1988) propose that, for Italian, the kind of sublexical representations which their results can be taken to support are normally accessed *indirectly*, from the entries for the full forms of words, rather than *directly*, from a form's meaningful subparts. A second, morphologically-based route, tapped in the recognition of non-words, is taken by these authors to represent a slower, backup procedure, used principally when we encounter new and unfamiliar words. Thus, they consider sublexical representations of morphology to be typical, but the processing of morphology to be atypical.

Caramazza *et al.*'s position relies partly on the assumption that words' full forms will be recognized faster than their parts. This assumption may not be justified for Italian, however. Recall the results of the short SOA studies in Italian cited above. In this language (and to some extend also in Dutch), when small stimulus-onset asynchronies were inserted in the presentation of words' letter strings, we found that initially showing some substrings of letters seemed to permit recognition to occur as quickly as a word's full form. This finding seems consistent with a notion of *direct* access to words' lexical bases, via handles or pointers to internal lexical representations as I described above.

Alternatively, if there are separate morphological and non-morphological routes from words' graphic forms to the internal lexicon, results from the short SOA paradigm suggest that a morphological route is about as fast as one based on full forms. Thus, speed does not seem to be the decisive factor. The kind of initial functional equivalence which we found in Italian between BEG substrings and full forms was obtained for words of both very high and rather low frequency of use (see Jarvella *et al.*, 1987). An appeal to morphological processing as an exceptional mode of lexical access (see also Butterworth, 1983) does not seem supported by such data.

Jarvella and Wennstedt (1993) also reported an extension of the kind of effect summarized in Table 2 to lexical bases and suffixes of words in real sentence contexts. Subjects were asked in their Experiment 2 to choose between pairs of continuations to a sentence in Dutch. Besides a well-formed continuation (e.g., 'snoepje', 'piece of candy'-sg, in the context of a little child being given a ___), a choice pair included a foil, the nature of which was varied. The foil was a word, which contained a stem and inflection both of which were unacceptable in the sentence context (e.g. 'wolken', 'cloud'-pl), which contained a semantically anomalous stem but grammatical inflection (e.g., 'wolk', 'cloud'-sg), which contained an ungrammatical inflection but acceptable stem ('koekjes', 'cookie'-pl), or which contained a stem and inflection both of which were acceptable (e.g., 'koekje', 'cookie'-sg). Thus four conditions were defined, in terms of the separate well-formedness of a foil's lexical base and suffix.

The choice decision latencies obtained in this study showed the same pattern as found by Caramazza *et al.* and by Jarvella and Wennstedt for judgements on non-words in lexical decision. Reactions were fastest (averaging about 1.0 sec) when a foil item's stem and its inflection both violated contextual constraints in the sentence, were of intermediate speed (averaging 1.2–1.3 sec) when only stem or the inflection was unacceptable, and were slowest (1.5 sec) when neither the stem or inflection was unacceptable. These results suggest that morphological processing, as revealed in the study of partially regular non-words, extends to real words in sentence contexts, if subjects are asked to make grammatical decisions.

ANTICIPATION OF WORDS' GRAMMATICAL FEATURES

In sentence parsing, use of grammatical endings on words should be a common perceptual strategy (e.g., Bever, 1970; Clark and Clark, 1978). A final question I want to raise here is whether, in skilled reading, adults will *anticipate* grammatical features of words carried by final suffixes. That is, how likely is it that morphological structure is partly imposed on a wordform from the linguistic representation a reader is building of a sentence, rather than wholly derived from the form's stimulus properties.

In describing skilled reading (vs. listening, cf. Marslen-Wilson and Tyler, 1980), some researchers have preferred the idea that wordforms are recognized fully bottom-up, from stimulus information available; that good readers identify words fully from their visual forms rather than by partly guessing them, on the basis of context (see, e.g., Gough, 1983, Stanovich, 1980). I would like to take up this issue with respect to morphology, and give a partly dissenting opinion.

In parsing, a syntactic representation of the string of words which compose a sentence need not be derived strictly from the bottom up. A phrase marker could be constructed partly going 'over the top' of nodes in a parsing tree (see, e.g., Johnson-Laird, 1983; Kimball, 1973). In such an anticipatory process, grammatical features of upcoming parts of a constituent which is incomplete might be partly foreseen. In English, for example, if an NP begins with a plural determiner, prior to any prepositional modifiers, a plural head noun can be expected.

I would like to illustrate that grammatical features of a word in text *can* often be predicted from lefthand sentence context, even though just what a word's lexical base is may be difficult to anticipate. The kind of text redundancy which this phenomenon represents plausible affects the reading process. For example, it may allow readers to spend less visual attention analysing word-final suffixes which bear information about features such as word class (for some relevant Finnish data, see Hyönä *et al.*, 1989). Evidence from Swedish for such a process comes from recent studies of moving-window reading done from a computer screen (Jarvella and Kalliokoski, 1991). Findings from this work appear possible to accommodate within a theory of reading that postulates that word recognition is organized more generally around the detection of morphologically-based handles on words, i.e., also when words are read in context.

This issue is further connected to the question of how word recognition and higher-level processing in reading are interrelated. If grammatical processing is done primarily bottom-up and is based on the prior identification of full-forms, one might expect the processing of grammatical endings on words to be not very different than processing of their beginnings. On the other hand, if word recognition were based on the detection of morphological handles for words, then some form of grammatical analysis might modify or partly replace a second stage of lexical processing concerned with recognition of a wordform's ending (cf. Zola, 1984).

The critical research here (Jarvella and Kalliokoski, 1991) was concerned with whether readers will recognize a word in print without (before) seeing its final letters. Both off-line and speeded on-line types of reading tasks were employed. In this work, we tried to choose material which was representative of the language studied, Swedish, and its morphology. The words and contexts which we studied came from actual stories in newspapers and magazines. Each subject read a short set of 10 texts averaging about 75 words each. There was one target in each version of a text studied.

The research was done in three phases. First, we presented the story material in a cloze procedure (text-fill-in) task, second, we presented it in a kind of visual gating task, and third we presented it in a word-monitoring environment.

The cloze procedure phase was included to see whether, from lefthand context alone, target words in which we were interested (which were nouns and verbs) could be guessed. Only 8.7% of items (the verbatim word targets from the text) were correctly guessed in this situation. Sixty percent of the contexts which we studied in fact elicited no responses in this cloze task whose stems were semantically even related to targets. For the other 40% of contexts, some responses showed semantic similarity with targets (mean rating of 3.4 on a four-point scale, where 1 = target, 2 = a synonym, 3 = semantically related and 4 = fully unrelated). Below, I will refer to these two groups of target words as being UNPRED(ictable) and partially PRED(ictable). Word length averaged about 7.8 letters for both PRED and UNPRED targets.

The low predictability of target's stems is not too surprising, and agrees fairly closely with an estimate reported for English by Gough (1983). What was striking in the cloze task results was that fully 88% of subjects' responses were of the same grammatical class as targets, and of these, 94% had the same features carried by wordforms used as targets (number and definiteness for nouns, tense and voice for verbs). Thus, grammatical features of words were highly predictable in text, even if words' lexical bases were not.

The second phase of the research was aimed at seeing how many letters from a target word a reader would need to see before she could guess what the word was. Here, a task which is a reading analogue of Grosjean's (1980) gating task for speech was used. Subjects read the texts in a self-presented fashion on a computer screen. When they arrived at a target word's location, they were asked to guess the word having seen its first letter, its first two letters, its first three letters, etc. On average, subjects in this situation guessed PRED items correctly after seeing 29% of their letters and UNPRED items after 50% of their letters. Thus, they did not need to see the larger part of a target to be able to guess what it was. The average point at which the word was correctly guessed was before the boundary in a word separating its lexical base from its grammatical ending, and even before the point where, out of context, the word's root could be determined even in principle.

The third and final phase of the research was aimed at asking whether, while reading at a reasonable speed, subjects would be able to identify a target word they were seeking before its graphic form was fully visible. In this phase, we simulated a 7-character-wide moving-window on a computer screen which moved through a text from left to right at a rate of one character every 60 msec (16.7 characters, and about 4 syllables per second). Using this mode of visual presentation in previous work (Jarvella *et al.*, 1989), we have shown that skilled readers can read quite well, both silently and orally, and that young readers are also aided in detecting grammatical structure in text (Jarvella *et al.*, 1992).

In the previous moving-window research, we approached the issue of how fast a reader understands when reading partly by asking whether expressions are interpreted while they are still physically present before the eye. Using a 9-character-wide window and a 20 letter per second presentation rate, Jarvella *et al.* (1989) found that senior high school readers who were asked to monitor a story for references made to a central character generally did not seem to interpret short names and pronouns until sometime *after* they had viewed these expressions. Subjects recorded their monitoring responses on only a rather small minority of expressions within 125 msec after the final moment that a target was visible as a whole in the moving window, an interval which we took as being long enough to execute the manual push-button reaction required. Thus, the reference-assigning process seemed to be somewhat delayed with respect to presentation of the visual stimulus.

A question addressed in the present study was whether, in a word-monitoring task, the speed of subjects' responses would suggest somewhat delayed parsing of grammatical structure in sentences, plausible based on full 'bottom-up' analysis of word targets. Or, alternatively, would roughly the opposite be the case, and the parsing process exert an effect on word perception, such that, in context, readers would not need to see endings on word targets before they identified them?

TABLE 3

Mean word-monitoring latency (msec) measured from full target visibility, and percent responses given before a word's final letter was presented.

Condition	PRED words		UNPRED words	
	Mean latency	%	Mean latency	%
BASELINE	193	6	252	1
DELAY	59	44	139	25

Source: Jarvella and Kalliokoski (1991).

This is a difficult issue, and I cannot give sufficient details of the experiments that we performed to be able resolve it here very comprehensively. However, let me point out that the issue can be approached by controlling the visual presentation of a target word, and exploring the likelihood of a reader giving a monitoring response by some theoretically significant moment in time. That moment could be taken, for example, to be the moment the final letter in a word target enters and becomes visible in the moving-window, since before then no decision can be based on having seen a word's final letter(s). In practice, however, one can also take a somewhat later point as critical, since, as before, the subject needs to execute a manual response once he makes a decision.

Word-monitoring experiments were performed by Jarvella and Kalliokoski in slightly different visual conditions on five groups of 20 adult subjects. The texts were those studied in the cloze-gating tasks discussed above. A given subject received four texts containing PRED target words and six texts containing UNPRED target words. In some conditions, the rate of change in the moving window was as stated above; in others, rate was subtly reduced during a target's presentation, so that its final letters were displayed 200 msec later than normal with respect to the lefthand context.

Table 3 summarizes results obtained for two dependent variables: (1) mean word-monitoring latencies in four major conditions that we defined, measured from the moment a target's last letter was first displayed in the moving-window used; (2) the percentage of responses registered before that moment. It can be seen from the table that PRED words were recognized somewhat faster than UNPRED words, and that somewhat more PRED words were responded to before full target visibility. Secondly, introducing a delay in the moving-window's progress in the environment of a target word clearly had the effect of speeding word-monitoring latencies with respect to the signal, increasing the likelihood of recognizing a target before all its letters were present on the screen.

Both parameters in Table 3 are shown before allowing any extra time assumed to be needed for a subject to register her response. If one takes this interval to be around 125 msec, this amount should be subtracted from the reaction times shown. Most responses were registered within 125 msec from the moment the final letter in a target became visible in all conditions shown in Table 3 except the UNPRED BASELINE condition. In that condition, some 30% of responses were given by this deadline. That is to say, most of the time a subject did not seem to need to see the full target word before deciding to respond. Neither were there more than a handful of false alarms registered.

On the face of it, the results of the Jarvella–Kalliokoski experiments show that the parsing process can guide perception of the ends of printed words in sentences read in a text context. The lexical processing of words' endings suggested earlier in this paper for single-word reading may be mirrored in reading of text by a morpho-syntactic procedure at a higher level. In both cases, a perceptual handle for a wordform may be the main target of printed word recognition.

In the more recent moving-window experiments reviewed here, reading rate was a little slow to be able to conclude that the ends of words in text are generally anticipated in reading. Imposing a slight delay on the flow of stimulus information may have allowed the reader's interpretation of the text to overtake the process of word recognition, and push the point of recognition backwards into a wordform. However, the higher-level process which these studies reveal cannot be running very far behind the graphic input. A mechanism which feeds on grammatical features from local context may help drive full-form recognition even when the rate and quality of stimulus input are maintained.

To summarize, data are beginning to accumulate from several languages in Europe which suggest that skilled reading involves morphological processing. The three kinds of morphological processes I have dealt with here, recognition of perceptual handles on words, processing of lexical bases and affixes in partly regular forms, and recognition of words' final suffixes in the reading of text, seem to fit together rather well. The exact picture is still far from complete, but an overall outline seems to be emerging. Like English, the languages studied here have their own special properties. The fact that results from several languages tend to support similar conclusions, however, is a hopeful sign. Establishing some general principles of skilled reading should also help promote the study of reading disorders.

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NOTES

[1] Taft defines the BOSS as a word-initial string consisting of the first stem morpheme of a word (that is, after any prefixes have been stripped), or the first syllable of the stem (where the first syllable is taken to include as many postvocalic consonants as the orthographic rules of the language permit in stem-final position), whichever is shorter (encountered first in a left-to-right parse). In practice, this means that, in English, the BOSS will always be either a root or a rootlike string. In a language with primarily bisyllabic roots, such as Finnish, it is unclear whether the principle underlying the BOSS would be orthographic or morphological.

REFERENCES

Bever, T. G.: 1970, 'The cognitive basis for linguistic structures', in J. R. Hayes (ed.), *Cognition and the Development of Languages*, Wiley, New York, pp. 279–362.

Butterworth, B.: 1983, 'Lexical representation', in B. Butterworth (ed.), *Language Production*, Academic Press, London, Vol. 2, pp. 257–294.

Caramazza, A., Laudanna, A. and Romani, C.: 1988, 'Lexical access and inflectional morphology', *Cognition* **28**, 297–332.

Clark, H. H. and Clark, E. V.: 1978, *Psychology and Language*, Harcourt Brace Jovanovich, New York.

Eriksen, B. A. and Eriksen, C. W.: 1974, 'The importance of being first: A tachistoscopic study of the contribution of each letter to the recognition of four-letter words', *Perception and Psychophysics* **15**, 66–72.

Forster, K. I.: 1976, 'Accessing the mental lexicon', in R. J. Wales and E. Walker (eds.), *New Approaches to Language Mechanisms*, North-Holland, Amsterdam, pp. 257–287.

Gough, P. B.: 1983, 'Context, form, and interaction', in K. Rayner (ed.), *Eye Movements in Reading: Perceptual and Language Processes*, Academic Press, New York, pp. 203–211.

Grosjean, F.: 1980, 'Spoken word recognition processes and the gating paradigm', *Perception & Psychophysics* **28**, 267–283.

Henderson, L., Wallis, J. and Knight, D.: 1984, 'Morphological structure and lexical access', in H. Bouma and D. G. Bouwhuis (eds.), *Attention and Performance X, Control of Language Processes*, Lawrence Erlbaum, Hillsdale, NJ, pp. 211–226.

Hyönä, J., Niemi, P. and Underwood, G.: 1989, 'Reading long words embedded in sentences: Informativeness of word halves affects eye movements', *Journal of Experimental Psychology: Human Perception and Performance* **15**, 142–152.

Jarvella, R. J.: 1990, 'Units below the word level in printed word recognition', in K. Jokinen (ed.), *SKY 1990*, The Linguistic Association of Finland, Helsinki, pp. 19–36.

Jarvella, R. J. and Job, R.: 1985, *Asynchronous Perception of Printed Words*, Report No. 26, Department of General Linguistics, University of Umeå.

Jarvella, R. J. and Job, R.: 1988, 'La percezione delle parole scritte', in T. de Mauro, G. S. Sensini and M. E. Piemontese (eds.), *Dalla Parte del Ricevente: Percezione, Comprensione, Interpretazione*, Bolzoni, Rome, pp. 173–180.

Jarvella, R. J., Job, R., Sandström, G. and Schreuder, R.: 1987, 'Morphological constraints on word recognition', in D. A. Allport, D. G. MacKay, W. Prinz and E. Scheerer (eds.), *Language Perception and Production*, Academic Press, London, pp. 245–262.

Jarvella, R. J. and Kalliokoski, L.: 1991, 'Recognizing words in print before you see them', in Ö. Dahl and K. Frarud (eds.), *Papers from the Second Nordic Conference on Text Comprehension in Man and Machine*, University of Stockholm, Stockholm, pp. 71–83.

Jarvella, R. J., Lundberg, I. and Bromley, H.: 1989, 'How immediate is language understanding? Investigating reading in real time', *Reading and Writing: An Interdisciplinary Journal* **1**, 103–122.

Jarvella, R. J., Lundberg, I. and Kalliokoski, L.: 1992, 'A comparative study of error detection in discourse', *Reading and Writing: An Interdisciplinary Journal* **4**, 79–94.

Jarvella, R. J., Mellenius, I. and Wennstedt, O.: 1990, 'Some linguistic determinants of Swedish word recognition', *Scandinavian Journal of Psychology* **31**, 281–290.

Jarvella, R. J. and Wennstedt, O.: 1993, 'Detection of partial regularity in words and sentences', *Scandinavian Journal of Psychology* **34**, 76–85.

Johnson-Laird, P. N.: 1983, *Mental Models*, Cambridge University Press, Cambridge.

Kimball, J.: 1973, 'Seven principles of surface structure parsing in natural language', *Cognition* **2**, 15–47.

Laudanna, A. and Burani, C.: 1985, 'Address mechanisms to decomposed lexical entries', *Linguistics* **23**, 775–792.

Lima, S. D. and Pollatsek, A.: 1983, 'Lexical access via an orthographic code? The basic orthographic syllable structure reconsidered', *Journal of Verbal Learning and Verbal Behavior* **22**, 310–332.

Marslen-Wilson, W. D. and Tyler, L. K.: 1980, 'The temporal structure of spoken language understanding', *Cognition* **8**, 1–71.

Rubin, S. G., Becker, A. and Freeman, R. H.: 1979, 'Morphological structure and its effect on visual word recognition', *Journal of Verbal Learning and Verbal Behavior* **18**, 757–767.

Sandström, G., Jarvella, R. J. and Schreuder, R.: 1990, 'The effect of delaying a word's final letters on its naming latency', *Linguistics* **28**, 375–396.

Seidenberg, M. and McClelland, J.: 1989, 'A distributed, developmental model of word recognition and naming', *Psychological Review* **96**, 523–568.

Stanovich, K. E.: 1980, 'Toward an interactive-compensatory model of individual differences in the development of reading fluency', *Reading Research Quarterly* **16**, 32–71.

Taft, M.: 1979, 'Lexical access via an orthographic code: The basic orthographic syllable structure (BOSS)', *Journal of Verbal Learning and Verbal Behavior* **18**, 21–39.

Taft, M.: 1987, 'Morphographic processing: The BOSS re-emerges', in M. Coltheart (ed.), *Attention and Performance XII: The Psychology of Reading*, Lawrence Erlbaum, Hove, pp. 265–279.

Taft, M. and Forster, K. I.: 1975, 'Lexical storage and retrieval of prefixed words', *Journal of Verbal Learning and Verbal Behavior* **14**, 638–647.

CHE KAN LEONG AND MARY E. PARKINSON

PROCESSING OF ENGLISH MORPHOLOGICAL STRUCTURE BY POOR READERS

ABSTRACT. This chapter discusses the productive aspect of morphological processing and the effect on reading proficiency in older children. The report summarizes the results of three main experiments using the semantic priming procedure plus an initial repetition priming experiment, all using reaction time measures, to explore ten- to twelve-year old 'poor' readers' sensitivity to, and knowledge of, derivational morphology. There is some evidence from the accurate and rapid vocal production of complex derived or base words that the depth of derivational morphology and the converse of segmentation to base forms play a role in reading performance in these children.

INTRODUCTION

Morphology is the study of the hierarchical and relational aspects of words and the operation on lexical items according to word formation rules to produce other lexical items. The main dimensions of morphological structure in English are inflection and derivation with compounding being minimally different from derivation.

In general, inflections do not change syntactical categories of their base forms; whereas derivations alter word-class membership. Inflections usually change limited sets of linguistic information such as tense and number; whereas derivations provide more powerful linguistic changes. Inflectional and derivational processes are handled by different formal properties of linguistic rules (Aronoff, 1976; Bauer, 1983; Scalise, 1984, 1988). These processes can be differentiated on the basis of *productivity* according to word formation and other rules; but precise and theoretically explicit differentiations are difficult (Matthews, 1974; Stemberger, 1985).

PRODUCTIVITY IN MORPHOLOGY

Productivity in morphology is a relative concept and refers to the processing of possible or new words, including possible but non-occurring words. Productivity depends, among other things, on the morphological class of words. Examples are that certain words accept word boundary affixes (#); while others, formative boundary affixes (+), according to the boundary theory (Chomsky and Halle, 1968), or considering these affixes as subsets

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of levels within the lexicon. The suffixation #NESS is semantically more coherent and more transparent than the suffixation +ITY and tends to be more productive (Aronoff, 1976).

Productivity is also affected by word token frequencies in relation to affixation ('hapax legomena' or the relevant affix occurring only once in the sample) of these word forms. This conception of productivity is shown mathematically by Baayen and Lieber (1991) in their elegant quantification of Dutch and English morphological productivity based on a large lexical database of broadly general language and naturally occurring texts. Baayen and Lieber emphasize that there are degrees of productivity predicated on the efficacy of factors determining the formation of new or possible words and that truly productive word formation processes should produce, in theory, an almost 'uncountable' number of new forms.

Word formation rules affecting productivity apply at certain points in grammar: some in the internal lexicon, some at the point of insertion in syntactic structures, some during the course of derivation, and yet others to the output of other word-formation rules. Examples are some complex words with no corresponding verbs such as ONSLAUGHT and SLAUGHTER with SLAY as the stem or root and not *SLAUGHT. There are morphemes with no constant meanings such as STRAWBERRY, GOOSEBERRY with two lexical morphemes with nothing to do with straw or goose. Then not all words with the form X+ABLE such as PROBABLE, POSSIBLE have base forms.

Furthermore, the same base form with the same derived orthographic form could have different stress assignments, thus yielding different meanings. An example is the base form COMPARE with the derived forms COMPARABLE (Y#ABLE) as in: "The two models are not comparable", meaning 'not capable of being compared', and COMPARABLE (X+ABLE) as in: "This is the comparable model in our line", meaning 'equivalent' (Aronoff, 1976, p. 127). Moreover, there are affixes with no constant meaning such that RE in RECEIVE, REDUCE, REFER, REMIT, REPEL does not refer to 'back'; nor does any of CEIVE, DUCE, FER, MIT, PEL have constant meanings.

Relational Lexical Information

One important dimension of word formation rules is lexical relatedness; and the sensitivity to the internal structure of existing words, new words and possible words may distinguish good and poor language learners and readers. This notion of relational lexical information assumes that knowing one lexical item should facilitate the learning of a new lexical item, or possible non-item through some transformation rules.

Two lexical items are related "if they share some morphemes, and if they share some element of meaning" according to the generative literature (Williams, 1981, p. 245). Furthermore, if X is related to Y by affixation, "in the morphological derivation of X, Y must appear as a *constituent* (that is, a *unit*) ... that is, the meaning of X above will be a simple function of the meanings of X and the affix" (Williams, 1981, p. 245, original emphases). On this account, a morphologically complex word such as DECISION is derived from the base form DECIDE via nominalization transformation rules, and EQUALITY is predictable from the base form EQUAL with vowel alternation and vowel reduction. The affixation of -EN to monosyllabic adjectives to transform them into de-adjective verbs such as BLACKEN, DAMPEN, HARDEN is subject to the phonological constraint that the base form of the word must end, except under certain circumstances, in an obstruent, optionally preceded by a sonorant.

POOR READERS' PROCESSING OF MORPHOLOGICAL STRUCTURE

Within the above framework of the productive role of morphology, especially derivational morphology, it is instructive to know if grade school poor readers are sensitive to morphological relationship and, if so, in what way. Further, the effects of different levels of orthographic and phonological transparency and opacity in the derivation process on these readers' reading performance may suggest approaches to differential diagnosis and remediation.

Related Studies

In an early study with two experiments, Jarvella and Snodgrass (1974) asked adult skilled readers to judge if pairs of words viewed simultaneously contained the same underlying stem morpheme. Of direct interest to the present report was their second experiment to test the phonetic effects on visual recognition of morphemes in word pairs. The different word pairs used ranged from 'no change' condition for the verb stem in both spelling and pronunciation in the derived form (e.g., PUNISH–PUNISHMENT), to the 'change' condition in pronunciation alone, and to both spelling and pronunciation changes. The alternations used between stems and derived forms apply a variety of linguistic rules such as spirantization, palatalization, devoicing, vowel shift, dipththongization and glide deletion (Chomsky and Halle, 1968). Results showed that adult readers took longer reaction time and made more errors in deciding if pairs of printed words shared the same stem morpheme when these word pairs differed in spelling and pronunciation.

In a study of the accuracy of adult subjects in their visual recognition of words presented tachistoscopically, Murrell and Morton (1974) found that facilitation effect was morphological rather than just lexical. Pretraining their subjects with a word corresponding to the morpheme from which the word is derived facilitated visual recognition almost as much as priming with an identical condition.

More recent studies focussing on productivity of morphological relationship in children include those of Freyd and Baron (1982), Sterling (1982), Wysocki and Jenkins (1987), Tyler and Nagy (1989), Gordon (1989), among others.

Freyd and Baron (1982) taught fifth and eighth graders a list of 'nonce' words to examine the mechanisms used by children to learn derived words. Half of the nonsense items were related by consistent derivational rules (e.g., if PROK meaning high, then PROKNESS meaning top); while the other half suffixed and non-suffixed forms had unrelated 'root' items such that knowledge of derivational rules would not be helpful. Freyd and Baron found that bright fifth graders showed evidence of knowledge of morphological relations, but average eighth graders did not. Results from their training experiment were encouraging but inconclusive because of the short training duration; a more reflective approach such as the use of analogies might be more effective.

Sterling (1982) asked 20 eleven-year-old children to use affixes to form novel derivations in the context of two written stories. For example, when given: "BILT: To hunt and kill a species of monster called a sproat", subjects were expected to derive "Men who bilt sproats are called bilt___" (BILTERS). Sterling's data show that productivity was more affected by high salience (those affixes that attach with a word boundary #) than by low salience (those affixes that attach with a formative boundary +).

Wysocki and Jenkins (1987) taught fourth, sixth, and eighth graders the meanings of infrequent words such as SAPIENT (to change) and tested their knowledge of suffixed derivatives such as SAPIENCE. The older students were found to be able to recognize the relationship between the suffixed derivatives and the target words taught. However, they would still need to make explicit knowledge of syntactic contribution of the suffixes in definitional tasks (e.g., their incorrect definition of SAPIENCE as WISE rather than WISDOM).

Similar findings of different aspects of knowledge about suffixes being acquired at different times were also obtained by Tyler and Nagy (1989) from their paper-and-pencil tasks administered to grades four, six and eight children to tap their knowledge of derivational morphology. Tyler and Nagy suggested that a basic level of lexical semantic knowledge (e.g., CREATOR related to CREATE) was attained by grade four children, but the knowledge of syntactic properties of suffixes (e.g., DAMPEN being a de-adjective verb because of -EN and DAMPNESS being a noun from DAMP#NESS) would develop later and would continue through grade eight. Moreover, 'neutral' suffixes (usually attached to free morphemes and are of the kind -NESS, -MENT, -IZE) were acquired before non-neutral suffixes (usually attached to bound morphemes and are of the kind -ITY, -OUS, -IVE).

The various results could be explained with reference to distributional knowledge constraining the hierarchical arrangement of base forms or stems and suffixes (e.g., *DERIVAL or *ARRIVATION). This is akin to the level-ordering approach to word formation processes to explain developmental differences in productivity of affixation types as proposed by Gordon (1989).

THE PRESENT STUDY WITH POOR READERS

Following the above logic, the present report with several experiments was predicated on the role of morphological structure as an important component in children's reading proficiency. The hypothesis was that poor readers compared with their controls would be less sensitive to derivational morphology and would be less efficient, as shown by reaction time (RT) measures, in processing derivational words. In particular, derivational words which are more transparent orthographically and phonologically (e.g., WARM–WARMTH) should be processed more correctly and with shorter RT than those words which are orthographically and phonologically more opaque (e.g., DEEP–DEPTH) (see also Gordon, 1989). The present study differs from related ones in examining grade school poor readers defined as those scoring at about the 25th percentile of scaled vocabulary and reading comprehension scores, and in using production or vocalization tasks rather than recognition or lexical decision tasks for the main experiments (Experiments 2, 3, and 4).

The methodology followed that of the priming procedure in exploring readers' sensitivity to, and knowledge of, morphological relationship. In Experiment 1 repetition priming was used. In this procedure each word and the related (or unrelated) word are presented twice for lexical decision judgment (the first item being the prime and the second item being the target). The general finding of the facilitation due to repetition is that inflectional and derivational items should also reduce target lexical decision latencies almost as fully as identical repetition primes. In Experiments 2, 3 and 4 the semantic or associative priming procedure was used. Subjects were primed on a microcomputer screen with derivational words (base or derived forms) embedded in short sentence frames. They were then required to vocalize accurately and quickly the appropriate derived or base forms of the primes to complete the sentence frames semantically and syntactically.

Facilitation due to Morphological Relatedness

Experiment 1: Subjects and Procedure

The main question asked in Experiment 1 was whether or not grade school poor readers, defined as those children at the bottom quartile of scaled vocabulary and comprehension scores on the Canadian Tests of Basic Skills (CTBS) (King, 1982), are also sensitive to morphological structures. Further, it was hypothesized that these poor readers, as compared with their chronological age controls, would show less facilitatory effects from repetition priming in the visual recognition of target lexical items.

The subjects were 18 grade 6 poor or below average (BA) readers compared with 23 age-matched above average (AA) readers, who scored at the top 75th percentile in reading on CTBS; and 23 grade 7 BA readers compared with 24 AA readers similarly defined. There was no difference in the mean chronological ages of the target and control groups grade for grade (grade 6 BA and AA subgroups with mean ages of 131 and 130 months, and grade 7 BA and AA subgroups with mean ages of 142 and 142 months respectively). There was, however, significant difference in the scaled vocabulary and comprehension scores.

The sensitivity to morphological relations by the below average and above average readers in the two grades was examined in three priming conditions plus a control or neutral condition. Reaction time measures in making lexical decision judgment were used as indices of efficiency or sensitivity. An example of repetition priming of the target LONE was: Neutral or Control Condition (C1) (lxxx priming lone), Same Condition (C2) (lone priming lone), Morphologically Related (derivational morphology) Condition (C3) (lonely priming lone), and Morphologically Unrelated Condition (C4) (loans priming lone). The prime and the target were separated by two intervening distractors consisting of both words and pseudowords three letters in length (e.g., ten, miz) and randomized across the subjects.

All the items were generated in lower case letters at the rate of 200 msec per item and displayed centrally on the microcomputer screen. There were 20 target words varying in length from 3 to 5 letters with their corresponding control (neutral), identical, morphologically related and morphologically unrelated words. The target words and their morphologically unrelated or unrelated primes were nouns, adjectives or adverbs and did not contain regular or irregular verbs, as regularly and irregularly related words were found to be primed differently, at least in auditory recognition (Kempley and Morton, 1982). The mean printed frequencies (Carroll *et al.*, 1971) for the three sets of twenty items for each of the Same Condition (C2),

TABLE 1

Means and standard deviations (in parentheses) of correct response time (msec) of morphological priming task by type of prime and reading level for below average and above average grades 6 and 7 readers.

Type of prime	Grade 6		Grade 7	
	Below Average (BA) and Above Average (AA) Reader Subgroups			
(20 items each)	BA	AA	BA	AA
Neutral (C1)	608 (135)	499 (105)	519 (123)	477 (133)
Same (C2)	624 (175)	509 (118)	546 (138)	462 (104)
Morphologically Related – MR (C3)	567 (136)	467 (110)	479 (128)	414 (92)
Morphologically Unrelated – MU (C4)	689 (181)	541 (98)	563 (139)	498 (133)
n	18	23	23	24

Morphologically Related (C3), and Morphologically Unrelated (C4) conditions were: 750, 106, and 619 respectively. The subjects were seen individually in a quiet room and were instructed to make the lexical decisions accurately and quickly. They were shown on the computer screen their response times and the message "Your answer is good" or "This is a good try", accompanied by different tones for their lexical decisions.

Results and Discussion of Experiment 1

The accuracy rates for the grade 6 BA, AA and grade 7 BA and AA subgroups were respectively: 92.33%, 90.56%, 91.90% and 93.08%; and for the four conditions were respectively: (C1) 92.36%, (C2) 93.60%, (C3) 93.64% and (C4) 88.25%. The correct RT scores after editing for outliers were subjected to a 2 (grade) by 2 (reading level) by 4 (priming condition) ANOVA with the last factor repeated. The means and standard deviations of the RT scores for the 2 grades, the 2 reading levels and the 4 experimental conditions are shown in Table 1.

The main effects for grades and reading level were significant (F (1,84) = 6.86, $p < 0.01$; & F (1,84) = 12.30, $p < 0.001$ respectively). The older and the above average readers were more efficient in making lexical decisions of primed target words as shown by their generally shorter latency scores. The main effect for priming conditions was also significant F (3,252) = 47.70, $p < 0.001$). The most facilitating priming condition was shown by the morphologically related words (C3), and the least facilitating condition by the morphologically unrelated words (C4). RT measures for

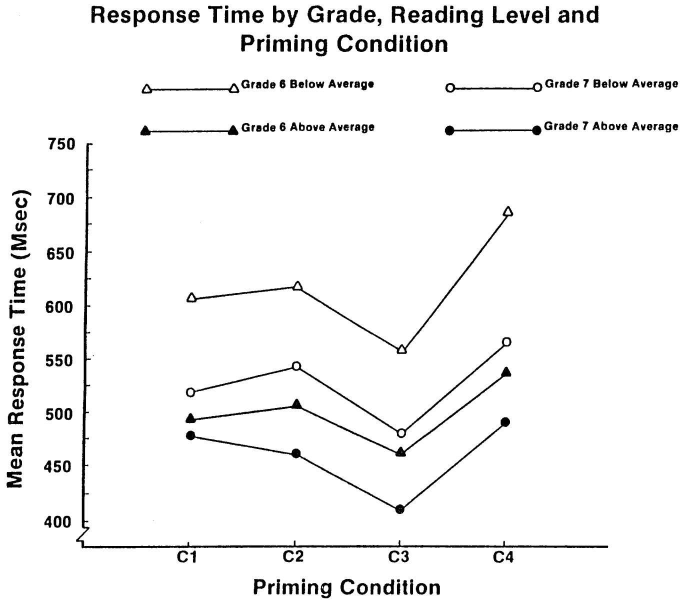

Fig. 1. Experiment 1 mean response latency by grade (6 and 7), reading level (below average (BA) and above average (AA)), and repetition priming condition (C1 Neutral or Control, C2 Same, C3 Morphologically Related and C4 Morphologically Unrelated).

targets primed by the same word (C2) and by the neutral items (C1) were intermediate between the latencies of C3 and C4. These patterns are shown graphically in Figure 1.

Results of Experiment 1 with the below average readers compared with their chronological age controls are in general agreement with those found with adults (Jarvella and Snodgrass, 1974; Murrell and Morton, 1974). The grades 6 and 7 readers in the present study were found to be sensitive to morphological relationship. They were least facilitated in their visual recognition of target words by physically related words but could perceive the correspondence between base forms of lexical items and their derived forms. While the lexical decision was improved by the presentation of morphologically related primes, this facilitation was greater for the above average and older readers, as can be expected. The enhanced facilitation of the morphologically derived words, even with lower mean printed frequency, as compared with the identical items as primes, is compatible with the findings of Murrell and Morton (1974), who argued for almost equal facilitation of root morphemes.

The present results suggest that readers may tap a deeper morphological or structural relationship rather than just visual similarity of primes and targets. The nature of this relationship in derivational morphology in poor readers would need to be further investigated, as attempted in the next three experiments.

Level-Ordered Processing of Derivation by Poor Readers

Sensitivity to word formation rules entails in one sense what Aronoff (1976) calls the 'semantic drift' or words of the kind that TRANSMISSION can drift from 'the action of transmitting' to mean part of the engine system of cars. In a deeper sense, this notion and the knowledge of morphological structure in language learners should emphasize functional grammatical processes that affect word formation and express concepts (Anderson, 1990). The next three experiments, using a semantic or associative priming procedure and a vocalization format, examined the source of productive knowledge of derivational morphology in grade school poor readers.

Experiment 2: Subjects and Procedure

Experiments 2 and 3 Derived Form Morphology and the related Experiment 4 Base Form Morphology were designed to explicate the more precise nature of productive knowledge of derivational rules in poor readers and spellers. The basic concept was predicated on the studies by Jarvella and Snodgrass (1974), Carlisle (1987, 1988) and Fowler *et al.* (1985).

The focus was on the rapid vocalization of derived forms of words from source base forms (Experiments 2 and 3) and of base forms of words from source derived words (Experiment 4), all embedded in short sentence frames as contexts. The subjects for Experiment 2 were essentially the same 88 children from Experiment 1 with 18 below average (BA) and 24 age-matched above average (AA) readers in grade 6, and 23 BA and 23 age-matched AA readers in grade 7. Since the experimental procedure for Experiments 2 and 3 were the same, except for different sets of base words and the sentences in which these words were embedded, the stimulus materials and procedure are outlined below for both of these two experiments.

Experiment 2 assessed individual subjects' knowledge of the derivation of words in sentential contexts under four conditions with 12 items each for a total of 48 items. The four conditions or levels were: (a) No Change condition in the place where stress occurs in the derived word (e.g., FINAL–FINALLY, HOPE–HOPEFUL); (b) Orthographic Change condition such as consonant doubling as a function of stress assignment in complex words (e.g., SUN–SUNNY, HAPPY–HAPPINESS); (c) Phonological Change condition involving vowel alternation pattern and vowel reduction (e.g., EQUAL–EQUALITY, HEAL–HEALTH); and (d) Both Orthographic and Phonological Change condition (e.g., EXPLAIN–EXPLANATION, TYPE–TYPICAL). The mean printed frequencies for the 48 base words were 523 per million and for their corresponding derived forms 105 per million according to Carroll *et al.* (1971).

The underlying notion of this experiment was to examine if the student could derive the different forms of the base word rapidly and accurately when primed with that base form embedded in a sentence context frame. These were some sample items with the sentence frames: No Change condition: FINAL: After trying many times, he won the game ____. (FINALLY); Orthographic Change condition: HAPPY: The rich man was very sick and sad; nothing could buy him ____. (HAPPINESS); Phonological Change condition: EQUAL: In a free country all people are equal and we value our ____. (EQUALITY); Both Change condition: EXPLAIN: He was late because he did not get up on time. This was a poor ____. (EXPLANATION). It should be noted that the sentences were designed in such a way that the to-be-pronounced words would always come at the end of the sentence frames as shown by the blanks and the appropriate punctuation marks.

For Experiments 2, 3 and 4 each source base word or derived word was generated in a random order at the same rate of 200 msec so as to approximate normal reading speed (Rayner, 1978) and remained on the microcomputer screen. The context sentence frame then appeared at the same rate per word and ended with an underlined blank followed by an appropriate punctuation mark. It was only at this juncture that the subject should vocalize the correct derived form (for Experiments 2 and 3) or the correct base form (for Experiment 4) that would complete the sentence frame both semantically and syntactically. The *onset* of the vocalization would terminate the timer, while preceding this the source base or derived word and the sentence frame remained on the screen.

The correctness or otherwise of the vocal response, taking into account vowel alternation and stress assignment; and morphological, semantic and syntactic correctness, was recorded on the microcomputer by the experimenter with a YES/NO key press. Feedback took the form of a computer message on the screen "Your answer is good/This is a good try" for correct or incorrect derived or base forms accompanied by different audial tones, and the actual response RT was also shown. The response latency from the end of the sentence frame, or more correctly, from the *offset* of the to-be-completed blank to the *onset* of the subject's vocalization provided precision timing. The RT measures were taken as indices of the efficiency with which subjects processed derivational morphology.

TABLE 2

Means and standard deviations (in parentheses) of correct vocalization latencies (msec) of derivation task by depth from base morphology to derivation and reading level for below average and above average grades 6 and 7 readers.

Depth from base to derivation morphology (12 items each)	Grade 6		Grade 7	
	Below Average (BA) and Above Average (AA) Reader Subgroups			
	BA	AA	BA	AA
No Change (C1)	6428 (2858)	3063 (2005)	4477 (2251)	1779 (828)
Orthographic Change (C2)	6817 (2638)	3368 (3227)	4792 (2784)	1720 (1069)
Phonological Change (C3)	7067 (2175)	3450 (2373)	5351 (2632)	2292 (1406)
Both Change (C4)	7182 (2605)	3132 (2440)	4788 (2632)	2215 (1109)
n	18	24	23	23

Results and Discussion of Experiment 2

The accuracy rates collapsing across reader subgroups for the 88 subjects were all around 69% with a slight drop to 68.4% for the Both Change derivational condition or level. However, the overall mean accuracy rates for the grade 6 BA and AA subgroups were 56.21%, 74.63% and for the grade 7 BA and AA subgroups were 64.39% and 79.23% respectively.

The vocalization latency scores for the correct responses were then edited for outliers and subjected to a 2 (grade) × 2 (reading level) × 4 (derivation condition) ANOVA with the last factor repeated. There were significant main effects for grade (F (1,84) = 13.39, $p < 0.001$) and for reading level (F (1,84) = 52.33, $p < 0.001$). There was also a significant main effect for derived morphology conditions in the expected direction (F (3,252) = 4.89, $p < 0.01$). The results show that below average and younger readers are less efficient in their processing of derived morphology; and the efficiency varies according to the level of orthographic and phonological transparency and opacity in the derivational process. The means and standard deviations of the correct vocalization latencies by depth from base morphology to derivation in relation to reading subgroups are shown in Table 2; and the patterns are displayed in Figure 2.

Experiment 3: Subjects and Procedure

Experiment 3 used another sample of similarly defined below average readers from a large sample of a two-phase, two cohort study of componential analyses of reading (Leong, 1988, 1992). There were 27, 19 and 29 BA readers in grades 4, 5 and 6, making a total of 75 poor readers. On

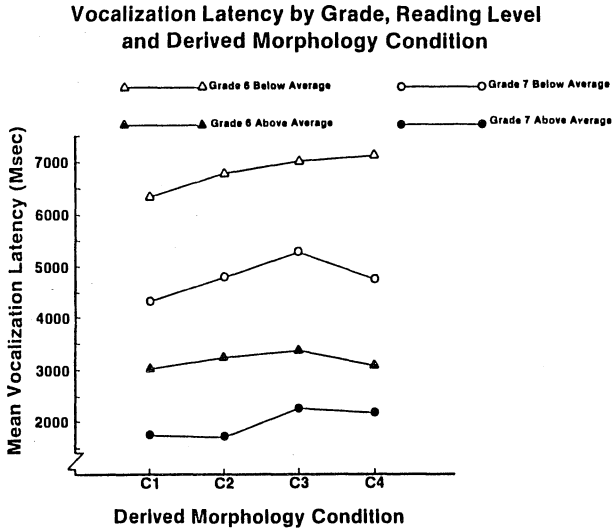

Fig. 2. Experiment 2 mean response latency by grade (6 and 7), reading level (below average (BA) and above average (AA)), and derived morphology condition (C1 No Change, C2 Orthographic Change, C3 Phonological Change, and C4 Both Orthographic and Phonological Change).

the basis of the aggregate reading and spelling scores of the Wide Range Achievement Test-Revised (Jastak and Wilkinson, 1984), these poor readers in each grade were further divided into those performing better in both reading and spelling (R+S+) subgroup, those performing worse in both reading and spelling (R-S-) subgroup, and a mixed subgroup. The experimental procedure was similar to that of Experiment 2, except that 10 different base forms embedded in short sentence frames were used for each of the No Change, Orthographic Change, Phonological Change and Both Orthographic and Phonological Change Conditions, making a total of 40 new base words in the four levels. Again, the children were asked to vocalize accurately and quickly the derived forms which would complete the meaning and construction of the sentences.

Results and Discussion of Experiment 3

For the total group of subjects, the overall accuracy rate was 65%. The correct responses were then edited for outliers and subjected to further analysis. Table 3 shows the means and standard deviations of the correct vocalization response latencies for the 75 poor readers by different conditions or levels of derivational morphology for the (R+S+), mixed, and (R-S-) reading/spelling subgroups in the three grades.

One of the two questions examined was the way in which different grades and different reading/spelling subgroups performed on the derived morphology task as inferred from their response times. The other question was the effect of the different morphological conditions or levels on these subgroups. To answer the first question, a 3 (grade) $\times$ 3 (reading/spelling ability) $\times$ 4 (derived morphology condition) ANOVA with the last factor repeated was carried out on the edited correct RT scores of the 75 poor readers. The main effects were all significantly different at the 0.0001 level with F (2,66) = 12.32 for grade, F (2,66) = 15.03 for reading/spelling ability, and F (3,198) = 36.17 for the depth of morphological conditions. The interactions were not significant. Orthogonal decomposition of the different conditions treated as increasing depth of derivation complexity further shows a cubic trend.

To further analyze this trend and to provide some answers to the second question above, a series of discriminant function analyses using the 4 conditions as discriminants were carried out for each grade. For the 27 grade 4 poor readers, there were no significant discriminants. For the 19 grade 5 poor readers, the Orthographic Change condition (C2) was highly significant (F (2,16) = 14.552). The canonical correlation of the four conditions in a linear combination with the reading tests was 0.803 and the discriminant function analysis correctly identified 63.2% of the total of 19 poor readers. The breakdown was 75% correct identification for each of the (R+S+) and (R-S-) subgroups and negligible contribution for the mixed subgroup probably because of the very small number there. For the 29 grade 6 poor readers, the same Orthographic Change condition (C2) was highly significant (F (2,26) = 10.245). The canonical correlation of the four conditions in a linear combination with the reading tests was 0.664 and the discriminant function analysis correctly identified 58.6% of the 29 poor readers (80% for the (R+S+) subgroup, 30.8% for the mixed subgroup, and 83.3% for the (R-S-) subgroup). The effect of the different levels of complexity of derived morphology on the performance of the reading/spelling subgroups is shown in Figure 3.

Experiment 4: Subjects and Procedure

The same 27 poor readers in grade 4, 19 poor readers in grade 5, and 29 poor readers in grade 6 took part in the complementary experiment. Experiment 4 base form morphology assessed individual subjects' productive knowledge of the base forms of the source derived words in sentence frames. The same four conditions as in the first experiment were used with 10 different complex, derived words embedded in 10 different sentence contexts for

TABLE 3

Means and standard deviations (in parentheses) of correct vocalization response time (msec) of derived morphology task by depth of derivation and reading/spelling level for below average grades 4, 5 and 6 readers.

Depth from base to derivation morphology (10 items each)	Grade 4 (n = 27)			Grade 5 (n = 19)			Grade 6 (n = 29)		
	Reading (R) and spelling (S) subgroups								
	(R-S-)	Mixed	(R+S+)	(R-S-)	Mixed	(R+S+)	(R-S-)	Mixed	(R+S+)
No change [in stress] (C1)	5839 (1942)	5596 (2454)	4667 (2283)	7184 (1452)	4581 (1955)	3788 (1160)	4644 (1689)	3022 (1019)	2493 (1042)
Orthographic Change (C2)	6372 (1444)	5838 (1253)	5025 (2069)	6395 (1388)	4361 (1030)	3393 (810)	4967 (1128)	2969 (898)	2512 (1274)
Phonological Change (C3)	6990 (2131)	6823 (1610)	5192 (2303)	7429 (2741)	5230 (1626)	4487 (1422)	5797 (2057)	3944 (1454)	3112 (1640)
Orthographic and Phonological Change (C4)	8915 (3491)	6919 (1555)	7274 (4130)	9177 (4993)	9071 (2569)	5576 (2403)	7762 (1845)	4945 (1279)	4323 (2463)
All 4 levels of depth	6231 (2017)	5576 (1272)	4133 (1208)	6559 (1691)	4593 (1102)	3838 (1001)	5562 (1911)	3130 (654)	2690 (1119)
n	9	8	10	8	3	8	6	13	10

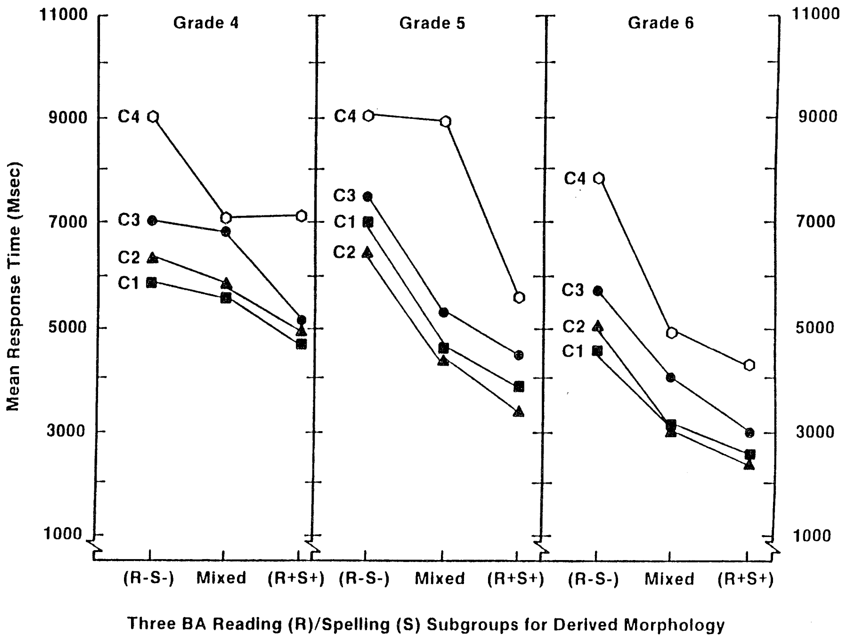

Fig. 3. Experiment 3 mean response latency by grade (4, 5 and 6), reading/spelling subgroup ((R+S+), mixed, (R-S-)), and derivational morphology condition (C1 No Change, C2 Orthographic Change, C3 Phonological Change, C4 Both Orthographic and Phonological Change) for 75 poor readers.

a total of 40 new derived lexical items. Some sample items were: (No Change condition: USUALLY: Winter rain in Vancouver is quite ____. (USUAL); Orthographic Change condition: FOGGY: They could not see very far because of the heavy ____. (FOG); Phonological Change condition: PERIODIC: I will be on holiday for the whole July ____. (PERIOD); and Both Orthographic and Phonological Change condition: ATHLETIC: He does well in school and in sports. He is a good student and a good ____. (ATHLETE). The mean printed frequencies for the 40 complex words and their corresponding base forms were respectively 160 and 388 per million (Carroll *et al.*, 1971).

The experimental procedure was similar to that of Experiments 2 and 3. All the 40 source items embedded in sentence frames were given in a random order individually to the 75 poor readers, who were asked to vocalize quickly and accurately for each item the correct base form of the source word so as to complete the sentence frame both semantically and syntactically.

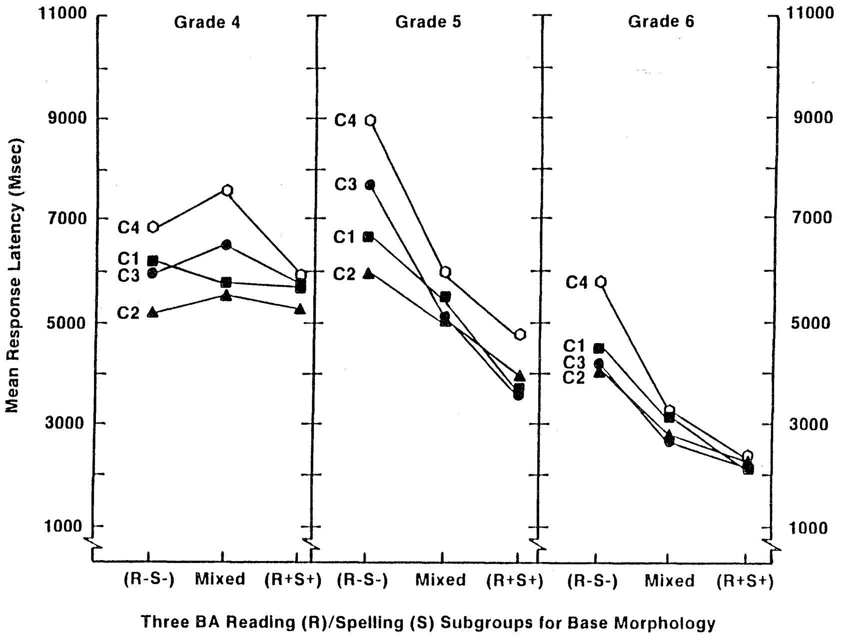

Fig. 4. Experiment 4 mean response latency by grade (4, 5 and 6), reading/spelling subgroup ((R+S), mixed, (R-S-)), and base morphology condition (C1 No Change, C2 Orthographic Change, C3 Phonological Change, C4 Both Orthographic and Phonological Change) for the 75 poor readers.

Results and Discussion of Experiment 4

The overall accuracy rate was 80%. The correct response latencies were then edited for outliers for further analysis. For the 75 poor readers in the three grades the mean RT measures in milliseconds of the correct answers and their standard deviations for the (R+S+), mixed, (R-S-) reading/spelling subgroups by the four conditions or levels of the base morphology transformation are shown in Table 4, and the patterns are displayed in Figure 4.

Questions similar to Experiments 2 and 3 were posed about the performance of the different grades and the reading/spelling subgroups on the base morphology task and the effects of the four conditions or levels on these poor readers. A 3 (grade) $\times$ 3 (reading/spelling ability) $\times$ 4 (base morphology condition) ANOVA with the last factor repeated shows significant main effects with F (2,66) = 12.02 for grade; F (2,66) = 5.59 for reading/spelling ability; and F (3,198) = 14.03 for base morphology condition. Again, orthogonal decomposition of the different conditions shows a cubic trend.

TABLE 4

Means and standard deviations (in parentheses) of correct vocalization response time (msec) of base morphology task by depth of processing and reading/spelling level for below average grades 4, 5 and 6 readers.

Depth from base to derivation morphology (10 items each)	Grade 4 (n = 27)			Grade 5 (n = 19)			Grade 6 (n = 29)		
	Reading (R) and spelling (S) subgroups								
	(R-S-)	Mixed	(R+S+)	(R-S-)	Mixed	(R+S+)	(R-S-)	Mixed	(R+S+)
No Change [in stress] (C1)	6254 (2075)	5814 (2712)	5717 (2839)	6737 (2829)	5536 (3251)	3678 (2172)	4512 (2744)	3149 (2059)	2168 (1093)
Orthographic Change (C2)	5266 (2325)	5683 (2456)	5384 (2728)	5907 (3082)	5110 (1705)	4025 (1929)	4072 (2082)	2794 (1806)	2262 (1708)
Phonological Change (C3)	6026 (2667)	6593 (2655)	5769 (3182)	7778 (4061)	5185 (1750)	3696 (1532)	4137 (1519)	2784 (1999)	2225 (688)
Orthographic and Phonological Change (C4)	6941 (3180)	7644 (2679)	5807 (3169)	9035 (2595)	6049 (2408)	4749 (2402)	5879 (1547)	3173 (1752)	2398 (1159)
All 4 levels of depth	5615 (2512)	5671 (2523)	4499 (1826)	6385 (3044)	4395 (992)	3783 (1496)	4601 (2571)	2275 (1238)	2302 (1250)
n	9	8	10	8	3	8	6	13	10

To further analyze this trend, a series of discriminant function analyses using the four base morphology conditions as discriminant functions were carried out. For grade 4, there were no significant functions. For grade 5 the Both Change condition (C4) was significant. The canonical correlation of the linear combination of the four conditions with the reading tests of 0.657 was significant. The discriminant function analysis correctly placed 68.4% of the 19 poor readers overall with 75% for the (R+S+) subgroup, 33.3% for the mixed subgroup and 75% for the (R-S-) subgroup. For grade 6, the first significant discriminant function was the Both Change condition $F\ (2,26) = 10.125$ and the second significant discriminant function was the Orthographic Change condition with $F\ (4,50) = 6.281$, after removing or partialling out the first discriminant function. The canonical correlation of the linear combination of the four conditions with the reading tests of 0.790 was significant. The discriminant function analysis correctly identified 62.1% overall of the 29 poor readers (60% for the (R+S+) subgroup, 46.2% for the mixed subgroup, and 100% for the (R-S-) subgroup).

GENERAL DISCUSSION OF MAIN EXPERIMENTS

Since the three main experiments (2, 3 and 4) complement one another and the mental processes required to produce the derived or base forms of the target words when primed by contexts could be considered similar, the results are discussed together. The study as a whole aims at examining poor readers' knowledge of lexical structure and the relations among words and within words or word constituents. The general approach of presenting a target, a sentence, and of requiring the production of the derived or base form of the target word is designed to measure the effect of comprehension of the sentence frame on the state of activation of the concept triggered by the target and the appropriate context. The efficiency in responses to different levels of derivation should provide an index of the productive knowledge of morphology in relation to reading proficiency. The use of naming latency measures rather than accuracy scores yields fine-grained results and emphasizes the chronometric nature in activating and utilizing word knowledge (Seidenberg, 1985).

Role of Morphological Conditions or Levels

The general findings of the main experiments (especially Experiments 3 and 4) point to the direction that poor readers differing in reading and spelling performance could be using different mechanisms or strategies in producing derived or base forms of morphology. This is shown by the overall faster reaction times of the (R+S+) subgroup over the mixed subgroup with the (R-S-) subgroup being the slowest for almost all the morphological conditions. There is also a developmental trend with the grades 5 and 6 children being more sensitive to the different facets of morphology as compared with the grade 4 subgroups.

While it is not always easy to interpret the magnitude of the RT differences, the significant ANOVA results give some evidence of the relative verbal inefficiency, and not so much mere slowness in articulating words on being primed, in these subgroups of children. It is verbal efficiency that plays an important role in reading performance (Leong, 1987; Perfetti, 1985).

With some slight variations and without loss of generality, the derivational morphology experiments show increasing processing time and, by inference, increasing cognitive and linguistic demand from the No Change (C1), through Orthographic Change (C2), Phonological Change (C3) to the Both Change (C4) morphological conditions (Tables 2, 3 and 4; Figures 2, 3 and 4). While the Orthographic Change condition seems to contribute more to the subgroup separation in Experiment 3; it is the Both Change condition that is more potent in the discriminant function analyses for Experiment 4. The increase in RTs generally parallels the progression from the morphologically less complex or more transparent (e.g., FINAL–FINALLY; USUALLLY–USUAL in C1) to the more complex or more opaque (e.g., EXPLAIN–EXPLANATION; ATHLETIC–ATHLETE in 4) derivation involving syllabic regrouping, vowel alternation and stress assignment from their respective target words.

This finding adds to Mackay's (1978) derivational complexity hypothesis, and is compatible with Gordon's (1989) proposal of explaining level-ordering in word formation in terms of developmental differences in productivity and affixation patterns. What is emerging is that in the visual recognition of target words in sentential contexts, and the accurate and rapid vocal production of complex derived or base words, depth of derivational morphology and the converse of segmentation and translation to base forms play a role and have an effect on reading and spelling performance.

It is instructive to note that when samples of the poor readers were asked to write down the derived forms immediately on completion of the individual vocalized items, they seemed to show an awareness of the relatedness between base to derived or derived to base forms of lexical items. Many of their spelling errors tended to preserve the base #/+ affixation boundaries (e.g., *CERTAINABLE, *EMPTYNESS, *MUSICTION, *DEEPTH). This observation of morphological over-generalization and the finding of inefficiency in articulating the derived or base forms suggest limitations in the precision of the morphological and orthographic processor of these readers. The imprecision is most evident with orthographically-complex and phonologically-complex clusters in the derivation process.

This informal analysis of the protocols of spelling errors also brings to mind the detailed delineation of 'morphemic dyslexia' by Seymour (1986). His Series III morphemic dyslexics showed varying degrees of morphemic impairment in the form of errors of word reading and partially phonetic or plausible phonetic attempts at spelling. Seymour interprets his delineations of 'phonological' or 'morphemic' dyslexia as separate or combined degradation of these domains and emphasizes processes rather than configuration differences.

Implications

Until more recently, morphology or word structure analysis involving inflection and derivation has been under-represented in the psycholinguistic literature. Current conceptual and empirical considerations have shown the multi-faceted nature of knowledge of morphology and the different mechanisms or strategies used by language learners in acquiring and developing this knowledge (Cutler, 1983; Henderson, 1985). There is support for different processing of inflectional and derivational morphology, as shown by Feldman (1991) in her investigation of morphological constituents of complex words in Serbo-Croatian. Her 'segment shifting task', where subjects were introduced to segment and shift morphemic (ER in DRUMMER) or pseudomorphemic (ER in SUMMER) segments onto target words and to name these new words accurately and rapidly, provided for non-morphological controls and helped to refine morphological relationship.

The present report does not deal with the broader aspect of morphographic parsing mechanisms such as the listing of morphemes together with formation rules as defining the potential words of the language (Halle, 1973), or the word-based hypothesis (Aronoff, 1976). Elsewhere, we have tested the Basic Orthographic Syllabic Structure (BOSS) principle of Taft (1979, 1987, 1988) with grade school and poor readers; and have found some evidence for the use of the BOSS morphographic parsing mechanism in these readers (Leong, 1989, Study 1; Leong and Parkinson, 1992).

Research Perspectives

From the theory and research perspectives, there is now considerable experimental evidence that morphological structure plays an important role in lexical representation (Caramazza *et al.*, 1988). Sensitivity to morphological structure also affects the organization of the mental lexicon of deaf subjects as studied by Hanson and Wilkenfeld (1985), and of aphasic patients as shown in the detailed cognitive and neuropsychological analyses of Caramazza and his colleagues (see Caramazza, 1988, 1991 for representative views). Caramazza and his colleagues have further educed experimental evidence on lexical representation and access from their Italian subjects using the more enriched morphological structure of Italian, as compared with the relatively impoverished English morphology.

In this regard, note should be taken of morphological constraints on word recognition from several European languages as reported by Jarvella *et al.* (1987). Research results in Italian, Dutch and Swedish generally support skilled readers' use of morphologically-defined letter clusters, but there are also differences in the forms stored (stems for Italians, morphemes for Dutch), lexical look-up and affixation processes (Jarvella, this volume; Jarvella *et al.*, 1987). For another morphologically 'rich' language such as Turkish, where stem formation by affixation to previously derived stems is productive, morphological parsing models must accommodate the recognition of roots before the recognition of suffixes (Hankamer, 1989).

Productive roots also have a special lexical status in Hebrew where infixation of vowel patterns between the consonants of the root morpheme changes its orthographic and phonological structure (Feldman and Bentin, 1992). Feldman and Bentin have demonstrated in their experiments that segmentation of root from word pattern in Hebrew is not necessarily tied to orthographic and phonological considerations and requires an extensive lexical knowledge. The interactive nature of orthography, phonology, morphology and meaning in printed word recognition from different orthographies affords rich sources of experimentation (Frost and Katz, 1992).

Educational Perspectives

From the educational and instructional perspectives, there is a need for systematic and explicit teaching of word knowledge and spelling, based on morphemic structure and origin of words and their productive rules, from elementary grades onwards (Carlisle and Liberman, 1987; Elbro, 1990, 1991; Henry, 1988, 1993; Rubin, 1988). This need is all the greater for students with reading and spelling problems. Carlisle (1987), for example, found her target 17 ninth grade students with learning disabilities, compared with 21 to 22 controls in each of grades 4, 6, and 8, to be more likely to disregard word structure and to show more depressed derivational morphology scores in their spelling.

In a detailed study of Danish developmental dyslexic adolescents, compared with reading-level matched normal controls, Elbro (1990, 1991) examined individual differences in the use of phonemic and morphemic principles or strategies. Of direct interest here was his use of a variety of reading tasks emphasizing accurate and rapid processing of various facets of morphology such as root morpheme, compounding and morphemic boundaries. He found wide variations among his dyslexics in the use of various morphemic principles quite independent of their use of phonemic principles. He suggested that these individual differences could be traced to the morphemic level and argued for greater emphasis on morphemic principles in reading and spelling.

In promoting knowledge of morphology, the focus should be on the hierarchical and relational aspects of constituents of words and not just the linear concatenation of subparts, as suggested in some teaching programs. This knowledge of morphological structure and the attendant phonological, semantic and syntactic alternations should enhance the proficiency of readers and spellers.

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REFERENCES

Anderson, S. R.: 1990, 'Sapir's approach to typology and current issues in morphology', in W. U. Dressler, H. C. Luschutzky, O. E. Pfeiffer and J. R. Rennison (eds.), *Contemporary Morphology*, Mouton de Gruyter, Berlin/New York, pp. 277–295.

Aronoff, M.: 1976, *Word Formation in Generative Grammar*, Linguistic Inquiry Monograph 1, MIT Press, Cambridge, MA.

Baayen, H. and Lieber, R.: 1991, 'Productivity and English derivation: A corpus-based study', *Linguistics* **29**, 801–843.

Bauer, L.: 1983, *English Word Formation*, Cambridge University Press, Cambridge.

Caramazza, A.: 1988, 'Some aspects of language processing revealed through the analysis of acquired aphasia: The lexical system', *Annual Review of Neurosciences* **11**, 395–421.

Caramazza, A.: 1991, *Issues in Reading, Writing and Speaking: A Neuropsychological Perspective*, Kluwer Academic Publishers, Dordrecht.

Caramazza, A., Laudanna, A. and Romani, C.: 1988, 'Lexical access and inflectional morphology', *Cognition* **28**, 297–332.

Carlisle, J. F.: 1987, 'The use of morphological knowledge in spelling derived forms by learning disabled and normal students', *Annals of Dyslexia* **37**, 90–108.

Carlisle, J. F.: 1988, 'Knowledge of derivational morphology and spelling ability in fourth, sixth, and eight graders', *Applied Psycholinguistics* **9**, 247–266.

Carlisle, J. F. and Liberman, I. Y.: 1987, *Does the Study of Latin Affect Spelling Proficiency?*, Haskins Laboratories Status Report on Speech Research SR-92, Haskins Laboratories, New Haven, CT, pp. 127–136.

Carroll, J. B., Davies, P. and Richman, B.: 1971, *The American Heritage Word Frequency Book*, Houghton-Mifflin, Boston, MA.

Chomsky, N. and Halle, M.: 1968, *The Sound Pattern of English*, Harper and Row, New York.

Cutler, A.: 1983, 'Lexical complexity and sentence processing', in G. B. Flores d'Arcais and R. J. Jarvella (eds.), *The Process of Language Understanding*, John Wiley, New York, pp. 43–79.

Elbro, C.: 1990, *Differences in Dyslexia: A Study of Reading Strategies and Deficits in a Linguistic Perspective*, Munksgaard, Copenhagen.

Elbro, C.: 1991, 'Dyslexics and normal beginning readers read by different strategies: A comparison of strategy distributions in dyslexics and normal readers', *International Journal of Applied Linguistics* **1**, 19–37.

Feldman, L. B.: 1991, 'The contribution of morphology to word recognition', *Psychological Research* **53**, 33–41.

Feldman, L. B. and Bentin, S.: 1992, *Morphological Analysis of Disrupted Morphemes: Evidence from Hebrew*, Haskins Laboratories Status Report on Speech Research SR-109/110, Haskins Laboratories, New Haven, CT, pp. 163–178.

Fowler, C. A., Napps, S. E. and Feldman, L. B.: 1985, 'Relations among regular and irregular, morphologically-related words in the lexicon as revealed by repetition priming', *Memory & Cognition* **13**, 241–255.

Freyd, P. and Baron, J.: 1982, 'Individual differences in acquisition of derivational morphology', *Journal of Verbal Learning and Verbal Behavior* **21**, 282–295.

Frost, R. and Katz, L. (eds.): 1992, *Orthography, Phonology, Morphology, and Meaning*, North-Holland, Amsterdam.

Gordon, P.: 1989, 'Levels of affixation in the acquisition of English morphology', *Journal of Memory and Language* **28**, 519–530.

Halle, M.: 1973, 'Prolegomena to a theory of word formation', *Linguistic Inquiry* **4**, 3–16.

Hankamer, J.: 1989, 'Morphological parsing and the lexicon', in W. Marslen-Wilson (ed.), *Lexical Representation and Process*, MIT Press, Cambridge, MA, pp. 392–408.

Hanson, V. L. and Wilkenfeld, D.: 1985, 'Morphophonology and lexical organization in deaf readers', *Language and Speech* **28**, 269–280.

Henderson, L.: 1985, 'Toward a psychology of morphemes', in A. W. Ellis (ed.), *Progress in the Psychology of Language*, Lawrence Erlbaum, London, Vol. 1, pp. 15–72.

Henry, M. K.: 1988, 'Beyond phonics: Integrated decoding and spelling instruction based on word origin and structure', *Annals of Dyslexia* **38**, 258–275.

Henry, M. K.: 1993, 'Morphological structure: Latin and Greek roots and affixes as upper grade code strategies', *Reading and Writing: An Interdisciplinary Journal* **5**, 227–241.

Jarvella, R. J., Job, R., Sandström, G. and Schreuder, R.: 1987, 'Morphological constraints on word recognition', in A. Allport, D. G. Mackay, W. Prinz and E. Scheerer (eds.), *Language Perception and Production*, Academic Press, London, pp. 245–262.

Jarvella, R. J. and Snodgrass, J. G.: 1974, 'Seeing ring in rang and retain in retention: On recognizing stem morphemes in printed words', *Journal of Verbal Learning and Verbal Behavior* **13**, 590–598.

Jastak, S. and Wilkinson, G. S.: 1984, *Wide Range Achievement Test*, revised edition, Jastak Associates, Wilmington, DE.

Kempley, S. T. and Morton, J.: 1982, 'The effects of priming with regularly and irregularly related words in auditory word recognition', *British Journal of Psychology* **73**, 441–454.

King, E. M. (ed.): 1982, *Canadian Tests of Basic Skills: Multilevel Edition/Levels 9–12/Forms 5 & 6*, Nelson, Toronto.

Leong, C. K.: 1987, *Children with Specific Reading Disabilities*, Swets & Zeitlinger, Lisse, the Netherlands.

Leong, C. K.: 1988, 'A componential approach to understanding reading and its difficulties in preadolescent readers', *Annals of Dyslexia* **38**, 95–119.

Leong, C. K.: 1989, 'The effects of morphological structure on reading proficiency – A developmental study', *Reading and Writing: An Interdisciplinary Journal* **1**, 357–379.

Leong, C. K.: 1992, 'Cognitive componential modelling of reading in ten- to twelve-year-old readers', *Reading and Writing: An Interdisciplinary Journal* **4**, 327–364.

Leong, C. K. and Parkinson, M. E.: 1992, 'Sensitivity to orthotactic rules in visual word recognition by below average readers', *Reading and Writing: An Interdisciplinary Journal* **4**, 1–17.

Mackay, D. G.: 1978, 'Derivational rules and the internal lexicon', *Journal of Verbal Learning and Verbal Behavior* **17**, 61–71.

Matthews, P. H.: 1974, *Morphology*, Cambridge University Press, Cambridge.

Murrell, G. A. and Morton, J.: 1974, 'Word recognition and morphemic structure', *Journal of Experimental Psychology* **102**, 963–968.

Perfetti, C. A.: 1985, *Reading Ability*, Oxford University Press, New York.

Rayner, K.: 1978, 'Eye movements in reading, and information processing', *Psychological Bulletin* **85**, 618–660.

Rubin, H.: 1988, 'Morphological knowledge and early writing ability', *Language and Speech* **31**, 337–355.

Scalise, S.: 1984, *Generative Morphology*, Foris, Dordrecht.

Scalise, S.: 1988, 'Inflection and derivation', *Linguistics* **26**, 561–581.

Seidenberg, M. S.: 1985, 'The time course of information activation and utilization in visual word recognition', in D. Besner, T. G. Waller and G. E. Mackinnon (eds.), *Reading Research: Advances in Theory and Practice*, Academic Press, New York, Vol. 5, pp. 199–252.

Seymour, P. H. K.: 1986, *Cognitive Analysis of Dyslexia*, Routledge & Kegan Paul, London.

Stemberger, J. P.: 1985, *The Lexicon in a Model of Language Production*, Garland Publishing, New York.

Sterling, C. M.: 1982, 'The psychological productivity of inflectional and derivational morphemes', in D. Rogers and J. A. Sloboda (eds.), *The Acquisition of Symbolic Skills*, Plenum Publishing, New York, pp. 179–185.

Taft, M.: 1979, 'Lexical access via an orthographic code: The Basic Orthographic Syllabic Structure (BOSS)', *Journal of Verbal Learning and Verbal Behavior* **18**, 21–39.

Taft, M.: 1987, 'Morphographic processing: The BOSS re-emerges', in M. Coltheart (ed.), *Attention and Performance XII: The Psychology of Reading*, Lawrence Erlbaum, London, pp. 265–279.

Taft, M.: 1988, 'A morphological-decomposition model of lexical representation', *Linguistics* **26**, 657–668.

Tyler, A. and Nagy, W.: 1989, 'The acquisition of English derivational morphology', *Journal of Memory and Language* **28**, 649–667.
Williams, E.: 1981, 'On the notions of 'lexically related' and 'head of word'', *Linguistic Inquiry* **12**, 245–274.
Wysocki, K. and Jenkins, J.: 1987, 'Deriving word meanings through morphological generalization', *Reading Research Quarterly* **22**, 66–81.

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INDIVIDUAL DIFFERENCES IN SIMILARITY JUDGEMENTS

ABSTRACT. Linguistic similarity perceptions differ within and across individuals, within and across languages. This is as true of spellers and readers as it is of speakers and hearers. In this paper we address the question of the similarity perceptions of German oral readers of German and English in order to determine the constraints on individual and group differences in similarity judgements in oral reading.

Three major findings are reported. First, we compared the similarity judgements among different individuals. We find that if one individual makes more 'different' judgements than another, then the number of his 'similar' and 'identical' judgements will be less than those of the other. Second, we compared unanimous ratings between different groups. We find that the only unanimous rating between different groups is 'different'. Evidently, the quality of group performance is directly related to the focus of the group on contrastive linguistics. Third, we studied the relative influences of the objective phonological characteristics on the individual subjects' judgements. We find the following precisor hierarchy, listed from most to least important: (1) German 'High', English 'Non-High and Non-Low', (2) German 'Vowel Tense' and English 'Vowel Non-Tense', and (3) German 'Non-Round Vowel' and English 'Non-Round Vowel'.

On the basis of the Determinacy Analysis of the relative importance of phonological components to similarity judgements, we establish the following effect: The importance of a component to a similarity judgement is relative to the co-occurring components. It emerges that Determinacy Analysis permits the in-depth investigation of such cases.

INTRODUCTION

Entities are similar if they have several features in common. Conversely, entities are different if they differ in one or more features. For example, a white cat is similar to a black cat in that they are both cats, but different in that one is white, whereas the other is black.

Entities are identical if they have the same features. In one sense of 'identical', entities are only identical to themselves. On this reading, two copies of the same book are not identical, because one copy is in one place, the other copy is in another, one purchased at one time, the other at another, one has been read, while the other has been left unopened, etc. In another, everyday reading, two entities are identical, if, for the purpose at hand, they are perceived to be the same. On this reading, the spelled word ⟨cat⟩ in one text is identical to the spelled word ⟨cat⟩ in another, and one person's pronunciation /kæt/ is identical to another's. 'Identical', in this sense, seems to mean something like 'same for the purpose at hand.'

There are individual differences in judgements of identity, similarity, and difference, i.e. one individual may rank two objects as identical, or

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similar, or different, while another may not. One listener may rank the vowel sounds in ⟨thought⟩ and ⟨though⟩ as similar, while another may rank them as different. Or one rater may rank the stressed vowel in German ⟨Miete⟩ as identical to the stressed vowel in English ⟨meter⟩, whereas another may rank them as only similar, or even different. Such ratings are observer-dependent judgements, judgements subject to variation from individual to individual. In other words, similarity judgements are relative, not absolute. There can be no question of a 'correct answer', because the ways in which the terms 'identical', 'similar', and 'different' are used are relative to their users.

In making similarity judgements, the observer must perceive some features as more relevant than others. Given a white cat, a black cat, a white dog, and a black dog, cat is grouped with cat, and dog is grouped with dog, rather than white cat with white dog, and black cat with black dog. This indicates that the similarity-grouping criteria are hierarchical – in this case that the feature [Animal] takes precedence over the feature [Color]. Entities are grouped first according to their essence rather than their accidence.

Similarity judgements are also context-dependent. If asked to group the above four animals according to their kind, cat goes with cat, and dog with dog. However, if asked to group them according to their color, the whites go with the whites, and the blacks go with the blacks. Accidence results in a grouping different from essence. Given the English vowel sounds, one subgroup is similar in frontness, another in height, another in roundness, etc. Consequently, entities are not just identical, similar, or different, but identical, similar, or different with relation to one or more attributes, or features, and such features constitute the contexts in which the similarity judgements are made.

Let us cast the above discussion within the determinacy-analytic framework. A determinacy is an expression of the form x, $z \rightarrow y$ – read "if x, then y" – where x is the argument, y is the predicate, and z the precisor (or binder) of x. The accuracy (I) of the determinacy is given by the formula I = $N(xy)/N(x)$, and the completeness (C) by the formula C = $N(xy)/N(y)$. When we say that A and B are similar, then they carry the same specifications on a shared set of features. Thus, difference and similarity presuppose identity. x is the feature(s) representing the compared entities, z is the feature(s)-precisor(s), and y is the similarity judgement itself, all for a given individual at a given time and place. Thus, judgements of identity, similarity, and difference – in fact all judgements – are the predicates of determinacies. For example, if under comparison are the vowels of English and German, then judgements become more similar if the German vowels are [+High] and the English vowels are [-High, -Low], and even more similar if the German vowels are also [+Tense] and the

English vowels also [-Tense]. In line with the above, it is the most inclusive class, here the vowel, that is the argument, and the features defining the less inclusive classes, here [High, Low, Tense], that are the precisors, or binders, raising the accuracy of the similarity determinacy towards 1.

It has been noted (Arnheim, 1974) that similarities must be perceived before differences. In the case of the cats and dogs, this means that like animals are grouped with like animals, then like colors grouped with like colors, before animals, then colors are perceived to be different. Thus, hierarchy appears to impose some order on similarity judgements.

Before proceeding with a discussion of similarity judgements in bilingual readers, we exemplify the relevance of similarity to the study of language.

First, take the case of the phonology of English inflection. As has been widely noted, schwa is present in some inflectional endings, such as those in *worded*, *parted*, *races*, *raises*, *judges*, and *churches*, but absent from others, such as *bragged*, *picked*, *cats*, and *dogs*. The thusfar undescribed fact is that schwa is present just in case the stem-final and ending-final consonants are similar in place of articulation. Stem-final /t, d/ are identical in place of articulation to ending-final /d/, and stem-final /s, z, š, ž, č, ˇ/ are identical in place of articulation to ending-final /z/. In both cases the stem-final and ending-final consonants agree in the phonological distinctive features of [Continuance, Anteriority, Coronality]. It is thus not the distinctive features, qua distinctive features, which correctly describe the presence or absence of schwa, but the fact that the stem-final and ending-final are *identically* specified with respect to those features. Under identity, schwa is present; under non-identity, schwa is absent. If there were no such harmony conditions on schwa, then the stem-final consonant would be inaudible, or dropped, with the result that the past tense would sound the same as the non-past, the plural the same as the non-plural, the genitive the same as the non-genitive, the possessive the same as the non-possessive, and the 3sg agreement the same as the non-3sg agreement. In other words, the function of the harmony conditions on schwa is to maintain semantic differentiation – phonological difference (with the presence of schwa) guarantees semantic difference, whereby the phonological difference is itself guaranteed by the phonological identity, or harmony, of the final consonants of stem and ending. Since the harmony condition on schwa preserves the identity of the stem-final and ending-final consonants, it functions to maintain the *self-identity* of the inflected words. An inflected word with a stem-final consonant that is identical to its ending-final consonant is more identical to itself than without. Furthermore, a sign consisting of 2 signifiers and 2 signifieds – say, /part/ 'leave' + /ed/ 'past' – is more identical to itself than a sign consisting of 1 signifier and 2 signifieds – say, /part/ 'leave' +

/Ø/ 'past'. The relation of identity thus sheds light on the relation between form and form, and form and content.

A second example of the linguistic relevance of relations of likeness comes from binding (Chomsky, 1981). Recall that α is said to bind β iff (i) α c-commands β and (ii) α and β are co-indexed. The application of binding is subject to the Conformality Constraint (CC) (Luelsdorff, 1991), which has the effect of inducing bidirectional motion between a binder tree B and a bound tree T. The CC imposes the form of B on the form of T, causing the binder of T to move into c-commanding position. Consider an example of motion from-B-to-T. In order for the /ae/ in /kaet/ to be spelled as ⟨a⟩, /ae/ must move into a position from which it c-commands the variable (A). Once the necessary movement has been executed, the position of /ae/ in T conforms to the position of its matching variable in B. Conversely, in motion from-T-to-B, the substance of T moves into the form of B. The binder /ae/ then binds (A) to ⟨a⟩, and /ae/ is thereby spelled as ⟨a⟩. Prior to binding, B and T are highly similar, differing only in the position of the binder /ae/ and absence of variables in T. On this view, this similarity causes the binder /ae/ in T to move into c-commanding position, resulting in the conformality of T with B. Then, the substance of T is identified with the substance of B, and /ae/ binds (A) to ⟨a⟩ in B. B and T are configurations on parallel planes between which there is a third plane P, the plane of permeability. Here, 'permeability' refers to the degree of ease of movement of B-to-T and T-to-B. The permeability of P is directly related to the similarity between B and T, i.e. the greater the similarity, the greater the permeability. On a somewhat different position, B's know which T's to form, and T's know which B's to substantiate, because, apart from binder position, the elements and relations of one are identical to the elements and relations of the other. On this second view, the binder and the bindable are parts of each other. B in the pair (T, B) binds itself, the B being self-identical to the T with which it is paired. In this case, B is a *self-identical whole* – a whole whose scalings (either reductions or expansions) are identical to itself.

A third example of the linguistic importance of likeness is drawn from developmental orthography (Luelsdorff, 1991). We studied the development of the spellings of (1) the short and long vowels, (2) the singled and doubled consonants, (3) the regular preterit, and (4) the orthography of the remaining inflections, and of contraction. It was found (Luelsdorff, 1991) that several pairs of structures exhibit reversals in complexity through time, and such reversals were explained by noting that the same structure may be processed by different strategies, whereby the complexity of the structure depends upon the nature of the strategy. For example, the orthographic preterit is more complex when processed phonologically than it is when processed semantically. The dips and drops in descending performance appear to be caused by ascending performance on structures whitin the same linguistic domain, where a linguistic domain is a set of linguistic structures having similar or identical properties. We conclude that structural similarity and identity also play central roles in language development.

A fourth example is based on a study of competence and performance errors made during the acquisition of English spelling by German schoolchildren (Luelsdorff, 1986, 1991). After the initial, traditional division into errors interlinguistic (German → English) and intralinguistic (English → English), there follows a processing strategic differentiation into (1) letter naming, (2) place of articulation of a letter name, (3) phoneme-grapheme correspondences (including complex → simplex and less frequent → more frequent), (4) sequence of letter names, and (5) cognatization vs. decognatization (both partial and total) (= false friends) (Luelsdorff and Eyland, 1991). Traditionally, these errors are classified as substitutions. From a different perspective, however, they are based on the relation of similarity. In particular, a target sound S1 is spelled by the letter L2 of the attempt sound S2, iff S1 and S2, or the name of S2, N2, are perceived by the learner to be similar or identical. In other words, the signifier of one sign may be used to represent the signified of another, iff the signifier or signified of the first sign are similar to the signified of the second. Cast in terms of determinacies, S1 → S2, iff S1 and S2 or N2 → identical or similar, where L = letter(s), S = letter sound, and N = letter name. On this formulation, the letter ⟨e⟩ (= L2) can spell the sound /e/ (= S1) in ⟨cornflakes⟩, because the sound of the English letter ⟨a⟩ (= /e/) is similar to the name (= N2) (or sound (= S2)) of the German letter ⟨e⟩ (= L2). Therefore, individual similarity judgements are essential to the description and explanation of linguistic errors, whereby such similarity judgements are observer-dependent.

Our fifth example of the linguistic relevance of similarity judgements is drawn from the domain of written language disorders. In a neuropsychological investigation of across-patient variability in spelling, Miceli (1991) contrasts the spelling of three patients: (1) I.G.R., with selective impairment of non-word spelling, (2) J.G., with selective impairment of word spelling, and (3) L.B., with impairment of written and oral spelling of words and non-words. The author suggests that I.G.R. has a Phonological Buffer deficit, J.G. a Graphemic Output Lexicon deficit, and L.B. a Graphemic Buffer deficit. The description is cast within a computationally explicit, modular model of the spelling process, suggesting predictions about the disorders arising from damage to various parts of the system. Within the framework of determinacy analysis, however, the variation among the patients receives a treatment more suggestive of the similarities and differences among them. Let S = sound(s), L = letter(s), N = name, and F = familiarity and, for the sake of simplicity, let each factor range over the values + or -. We can now say that (1) I.G.R. has the same determinacy (+S), -F → -L, -N, (2) J.G. the determinacy (+S) → -N. On the determinacy approach the unimpaired speller has the determinacy (+S) → +L, +N. On the modular approach (Caramazza and Hillis, 1991), the variation among the above three patients is best described in terms of impairment to one or another module within a modular of language. On the determinacy analytic approach, this variation is described in terms of the differences in the patients' determinacies themselves. These include: (1) I.G.R. and J.G. have determinacies whose arguments are bound by some value of F, whereas L.B. does not; (2) I.G.R. and J.G. have determinacies with complex (two-termed) predicates, whereas L.B. does not; (3) I.G.R. and J.G. have predicates which depend upon the value of F, whereas L. B. does not.

As noted above, differences presuppose similarities. Using the DA to rank the patients according to the decreasing order of similarity of their symptoms, we obtain (1) I.G.R. and J.G., then (2) I.G.R. or J.G. and L.B. Moreover, the rank order of the patients according to symptom complexity is (1) L.B., (2) J.G. and I.G.R. Within the DA-framework, these statements are detailed and precise. They become even more precise once frequencies are admitted into the analysis, as they ought to be. In fact, the observations become as precise as precise can be (Chesnokov and Luelsdorff, 1991). In order for modular design to achieve such precision, it must abandon the emphasis on modularity and adopt an emphasis on determinacy.

Sixth, and last, similarity is used to fit a model to the object modeled, and to compare and contrast the parts of the model itself. For example, Caramazza and Miceli (1991) suggest that graphemic representations be 'multidimensional' structures, rather than only strings of graphemes. Such structures are held to consist of levels, or tiers, including a graphemic identity tier, a CV-tier, a graphosyllabic tier, and information about consonant gemination. Among the evidence supporting the graphosyllabic tier is the fact that their patient's transposition errors occurred *within* the graphosyllable, rather than across graphosyllabic boundaries. The VC-tier is supported by substitution errors, which respected the C/V status of the substituted grapheme. The authors argue that the existence of a hypothesized level of representation derives support if a coherent account of errors can be provided by assuming damage to that level of representation. In this sense, the damaged theoretical architecture must be similar to the observed patterns of error. Moreover, it is noted that there are both similarities and differences between phonological and graphemic representations. Both are 'multidimensional', and both have similar units, but the categories of C and V behave differently in each. The authors maintain that graphotactic and phonotactic constraints are similar in principle, but different in content, at once illustrating judgements of similarity and difference about levels *within* their model. To conclude, this discussion of the nature of graphemic representation illustrates the necessity of similarity judgements between (1) model and object and (2) several levels within the model.

The examples discussed serve to show that judgements of similarity (including identity, self-identity, similarity, self-similarity, difference, indecision, and gradients thereof) are essential to both the knowledge of language and the study of language, i.e. linguistics. Despite this centrality, however, the nature of similarity in language and linguistics remain veiled in mystery. The reason for this neglect is the overassessment of the importance of rules of grammar thought to be known and used by ideal speakers in homogeneous speech communities. The focus in linguistics has been on rules, not on the individual judgements of identity and similarity which are prerequisite to their acquisition and use. New answers to old questions emerge once interest is shifted from the putative rules of ideal speakers to the similarity judgements underlying the constraints on determinacy differences within and among the knower-users of spoken and written language. With this shift in perspective, i.e. with the demise of the ideal grammar in the modular mind, will emerge new insights into individual linguistic differences, the ways in which they are related and constrained, and how these insights might best serve the communities from which they are derived. In the following we exemplify a method for taking individual differences in similarity judgements into account.

German schoolchildren typically study English as a foreign language to a greater or lesser extent. In order to be able to read and write, they must be able to identify English sounds with English letters and, moreover, differentiate the sounds and letters of English from the sounds and letters of German.

Different pupils and students have command of textbook material to different extents and to the same extent in different ways. For some, the requisite distinctions among sounds and sound-letter relations are hard to learn. For others, they are easy. The teacher ought to know the individual differences her pupils exhibit in order to make her instruction relevant and effective. She needs systematic methods to permit her to take individual differences into consideration. The purpose of this paper is to present such method.

SIMILARITY PERCEPTION OF GERMAN READERS

An Experimental Study

Pairs of words are presented. In each pair there are two words, one German and one English. In each word one or several letters are underlined, each letter corresponding to a German or English phoneme, depending upon the

TABLE 1

Sample test words.

	German	English
Word	M(au)s	c(au)ght
Grapheme	⟨au⟩	⟨au⟩
Sound	/au/	/ɔ/

TABLE 2

Similarity scale.

(1)	Different
(2)	Similar -
(3)	Similar
(4)	Similar +
(5)	Identical

case. Examples are given in Table 1, where the graphemes underlined in the experiment are enclosed in parentheses.

The subjects are successively presented with pairs of words in which the graphemes are underlined. The teacher asks the subjects to:

1. Pronounce, either silently or outloud, the sounds corresponding to the underlined graphemes, and
2. rate the similarity between the sounds corresponding to the graphemes along the 5-point scale in Table 2.

Among the questionnaires used to elicit the similarity judgements were 17 German words containing normatively different German vowels and 25 English words containing normatively different English vowels, for a total of $17 \times 25 = 425$ pairs of words. Some of these German and English test words and vowel graphemes and vowel sounds are given in Table 3.

Two groups of students participated in the experiment: Group 1 ($N = 9$) and Group 2 ($N = 7$). The particulars on each student in terms of initials, sex, age, and number of years of English are given in Table 4.

The primary data consisted, as usual, of a data matrix with objects in the rows and variables in the columns, and the values of the variables of each object in the cells.

TABLE 3

German and English words, graphemes and sounds

German			English		
R(a)t	⟨a:⟩	[a:]	empl(oyer)	⟨o3⟩	[o3]
B(i)ber	⟨i:⟩	[i:]	sh(i)p	⟨I⟩	[I]
B(o)den	⟨o:⟩	[o:]	b(oy)	⟨oy⟩	[o1]
R(u)te	⟨u:⟩	[u:]	c(au)ght	⟨au⟩	[o:]
R(e)st	⟨e⟩	[en]	p(oor)	⟨o2⟩	[u2]
W(u)rst	⟨ur⟩	[un]	pl(ayer)	⟨e2⟩	[e2]
Kl(ae)ger	⟨ae⟩	[ae]	l(ower)	⟨a3⟩	[a3]
M(au)s	⟨au⟩	[au]	b(oo)t	⟨oo⟩	[u]

TABLE 4

Composition of sample.

Group 1	Group 2
1. SF, Sex f, Age 21, Eng 9	1. AS, Sex f, Age 21, Eng 11
2. EW, Sex f, Age 22, Eng 8	2. SR, Sex f, Age 23, Eng 12
3. AW, Sex f, Age 20, Eng 8	3. CN, Sex f, Age 22, Egn 14
4. CW, Sex f, Age 21, Eng 9	4. BT, Sex f, Age 21, Eng 21
5. AS, Sex f, Age 20, Eng 9	5. EH, Sex f, Age 20, Eng 8
6. KS, Sex f, Age 20, Eng 8	6. AG, Sex f, Age 21, Eng 7
7. CR, Sex f, Age 20, Eng 8	7. CD, Sex f, Age 24, Eng 12
8. BR, Sex m, Age 22, Eng 9	
9. HR, Sex m, Age 57, Eng 45	

The pairs of graphemes in the words in the rows and the columns serve as the object of investigation. There is a total of 425 such objects (i.e. lines in the data matrix).

The dictionary of variables contains 25 primary variables. We list a sample in Table 5, beginning with variable No 2.

Several variables have been omitted from Table 5. For example, variable 1 indicates the various types of experimental situation. Not only vowel-sound pairs were under investigation, but also pairs of consonants. Moreover, we also investigated the intralinguistic situation within the German and English languages. All in all, six types were studied, namely

TABLE 5

The dictionary of variables.

Var. 2. Word in Row (German)		
R(a)t	⟨a:⟩	[a:]
B(i)ber	⟨i:⟩	[i:]
B(o)den	⟨o:⟩	[o:]
R(u)te	⟨u:⟩	[u:]
R(e)st	⟨e⟩	[eh]
W(u)rst	⟨ur⟩	[uh]
Kl(ae)ger	⟨ae⟩	[ae]
M(au)s	⟨au⟩	[au]
Var. 3. Letter(s) in Row (German)		
Var. 4. Sound(s) in Row (German)		
Var. 5. Word in Column (English)		
empl(oyer)	⟨o3⟩	[o3]
sh(i)p	⟨I⟩	[I]
b(oy)	⟨oy⟩	[oi]
c(au)ght	⟨au⟩	[o:]
p(oor)	⟨o2⟩	[u2]
pl(ayer)	⟨e2⟩	[e2]
l(ower)	⟨a3⟩	[a3]
b(oo)t	⟨oo⟩	[u]
b(ir)d	⟨ir⟩	[ir]
b(e)d	⟨e⟩	[e]
Letters in Column (English)		
Sound(s) in Column (English)		
Subject: SF, Sex: f, Age: 21, Eng: 9, G: 1		
No response		
Different		
Similar -		
Similar		
Similar +		
Identical		
Var. 10. Subject: EW, Sex: f, Age: 22, Eng: 8, G:1		
Var. 11. Subject: AW, Sex: f, Age: 20, Eng: 8, G:1		
Var. 12. Subject: CW, Sex: f, Age: 21, Eng: 9, G:1		
Var. 13. Subject: AS, Sex: f, Age: 20, Eng: 9, G:1		
Var. 14. Subject: KS, Sex: f, Age: 20, Eng: 8, G:1		
Var. 15. Subject: CR, Sex: f, Age: 20, Eng: 8, G:1		
Var. 16. Subject: BR, Sex: m, Age: 22, Eng: 9, G:1		
Var. 17. Subject: HR, Sex: m, Age: 57, Eng: 45, G:1		
Var. 19. Subject: AS, Sex: f, Age: 21, Eng: 11, G:2		
Var. 20. Subject: SR, Sex: f, Age: 23, Eng: 12, G:2		
Var. 21. Subject: CN, Sex: f, Age: 22, Eng: 14, G:2		
Var. 22. Subject: BJ, Sex: f, Age: 21, Eng: 21, G:2		
Var. 23. Subject: EH, Sex: f, Age: 20, Eng: 8, G:2		
Var. 24. Subject: AG, Sex: f, Age: 21, Eng: 7, G:2		
Var. 25. Subject: CD, Sex: f, Age: 24, Eng: 12, G:2		

TABLE 6

Typology of similarity perception

Var. 1. Typology of similarity perception
German vowels
German consonants
English vowels
English consonants
German and English vowels
German and English consonants

those listed in Table 6. Under investigation in the present work, however, is only the type designated by 'German and English Vowels'. This is the reason that the remaining variables were omitted from the dictionary of variables in the present case. Also omitted are variables 8 and 18, which are not important to the present discussion.

METHOD

The method used is the method of Determinacy Analysis (DA) and the DA-System, the computational system which realizes the DA. Interested readers are referred to Chesnokov and Luelsdorff (1991) and the relevant references cited therein.

The DA-system permits the easy formulation of new, secondary variables, which influence more detailed formulations of and solutions to the problems at hand. In the present case we formulated new variables and added them to the original dictionary of variables given above. All in all, 25 new variables were added, namely the ones listed with their values in Table 7.

RESULTS

In the following we present our major findings.

Individual Similarity Judgements

For each subject we obtained the distribution of all the rated objects along the scale given in Table 2. These distributions characterize the individual

TABLE 7

Secondary variables and their values.

Var. 29. Major sound classes in row
German vowel sound
German consonant sound
German liquid sound
German glide sound
Var. 30. Height of sound in row
German high sound
German non-high and non-low sound
German low sound
other
Var. 31. Tenseness of vowel sound in row
German tense vowel
German non-tense vowel
other
Var. 32. Anteriority of consonant sound in row
German anterior consonant sound
German non-anterior consonant sound
other
Var. 33. Coronality of consonant sound in row
German coronal consonant sound
German non-coronal consonant sound
other
Var. 34. Major sound classes in column
English vowel sound
English consonant sound
English liquid sound
other
Var. 35. Height of sound in column
English high sound
English non-high and non-low sound
English low sound
other
Var. 36. Tenseness of vowel sound in column
English tense vowel
English non-tense vowel
other
Var. 37. Anteriority of consonant sound in column
English anterior consonant sound
English non-anterior consonant sound
other

TABLE 7

(Continued)

Var. 38. Coronality of consonant sound in column
English coronal consonant sound
English non-coronal consonant sound
other
Var. 39. Similarity estimate of SF on gross scale
No response
Different
Similar
Identical
Var. 40. Similarity estimate of CN on gross scale
No response
Different
Similar
Identical
Var. 41. Comparison of SF and CN
SF = CN
SF: similar, CN: different. SF < CN
SF: identical, CN: different. SF ≪ CN
SF: identical, CN: similar. SF < CN
SF: different, CN: similar. SF > CN
SF: similar, CN: identical. SF > CN
Var. 42. Height of German and English sound
G & E: high
G & E: low
G & E: non-high & non-low
G: high, E: non-high & non-low
G: high, E: low
G: non-high & non-low, E: high
G: non-high & non-low, E: low
G: low, E: non-high & non-low
G: low, E: high
Var. 43. Tenseness of German and English vowel
G & E: vowel tense
G & E: vowel non-tense
G: vowel tense, E: vowel non-tense
G: vowel non-tense, E: vowel tense
other
Var. 45. Coronality of German and English consonant
G & E: coronal consonant
G & E: non-coronal consonant
G: coronal consonant, E: non-coronal consonant
G: non-coronal consonant, E: coronal consonant
other

TABLE 7

(Continued)

Var. 46. German vowel backness (in row)
German back vowels
German non-back vowels
other
Var. 47. English vowel backness (in column)
English back vowel
English non-back vowel
other
Var. 48. German vowel roundedness (in row)
German round vowel
German non-round vowel
other
Var. 49. English vowel roundness (in column)
English round vowel
English non-round vowel
other
Var. 52. Estimations in Group 1
No response, G:1
Different, G:1
Similar -, G:1
Similar, G:1
Similar +, G:1
Identical, G:1
other, G:1
Var. 53. Estimation in Group 2
No response
Different, G:2
Similar -, G:2
Similar, G:2
Similar +, G:2
Identical, G:2
other

situation of each subject. They show the extent to which each subject is able to differentiate the sounds of the German and English languages in oral reading.

Example 1. The distribution of the objects (pairs) along the points of the scale obtained for subject SF from Group 1:

TABLE 8
Similarity judgements of SF

9 Subject: SF, Sex: f, Age: 21, Eng: 9, G: 1		
0. No response	6 y	1.412%
1. Different	128 y	30.118%
2. Similar -	169 y	39.765%
3. Similar	90 y	21.176%
4. Similar +	27 y	6.353%
5. Identical	5 y	1.176%
	425	100.000%

Example 2. The distribution of objects (pairs) along the points of the scale obtained for CN from Group 2:

TABLE 9
Similarity judgements of CN

21 Subject: CN, Sex: f, Age: 22, Eng: 14, G:2		
1. Different	360 y	84.826%
2. Similar -	26 y	6.112%
3. Similar	22 y	5.172%
4. Similar +	17 y	4.000%
	425	100.000%

A comparison of Tables 8 and 9 indicates that CN differentiates the vowels sounds of German and English much more strictly than SF. A total of 425 pairs of sounds were rated. CN rated 360 cases (85%) of paired sounds as different, whereas subject SF rated only 128 cases (30%) as different.

Group Similarity Judgements

Variables 52 and 53 indicate how many objects were judged absolutely identically by all the members of Group 1 (52) and Group 2 (53), and how many objects were not judged absolutely identically (the point 'other' on the scale). Table 10 shows the distribution of objects according to the values of these variables in Group 1 and Group 2.

From the above it is clear that there is only one rating which was unanimously assigned by the members of Group 1 and 2, namely, 'different'.

TABLE 10

Judgements of 'different' and 'other'.

a.	Group 1		
	52 estimations in Group 1		
	1. Different: 8:1	66	15.529%
	6. Other: 8:1	359	84.471%
		425	100.000%
b.	Group 2		
	53 estimations in Group 2		
	1. Different: 8:2	239	56.235%
	6. Other:	186	43.765%
		425	100.000%

There was not a single uniform evaluation in either Group 1 or Group 2 in terms of the other ratings at all. In other words, there is not a single pair which is judged to be either 'similar +', 'similar', 'similar -', or 'identical' in either Group 1 or Group 2.

Moreover, there are far more uniform judgements of 'different' in Group 2 than in Group 1. In Group 2 there are 239 (56%), whereas in Group 1 there are only 66 (16%). This may be explained by the fact that there are fewer subjects in Group 2 ($N = 7$) than in Group 1 ($N = 9$), since, in this case, it is easier for Group 2 to achieve unanimity. This explanation, however, seems inadequate to explain such a striking difference in the number of unanimous judgements of 'different'. A second, more adequate explanation resides in the fact that Group 2 consisted of students enrolled in a course in German–English Contrastive Analysis, whereas Group 1 consisted of students enrolled in a course in Reading and Spelling.

Objective and Subjective Characteristics

The objective characteristics of the sounds constituting the pairs to be judged naturally exert an influence on the subject's selection of one or another rating. Such influence is an a priori judgement. The influence of this a priori judgement was tested. As a result, information was obtained on how the objective characteristics of the sounds in a pair influence their subjective differentiation.

The data on such influence assumes the form of the determinacy Table 11.

TABLE 11

Determinacy table 1.

9 Subject: SF, Sex: f, Age: 21, Eng: 9, G: 1
Different

Y = 128

X							
42	43	50	51			X	XY
*4(0.33)	3(0.25)	2(-0.00)	2(0.17)	0.83	0.04	6	5
3(0.30)	2(0.33)	3(0.33)	3(0.00)	1.00	0.02	3	3
#4(0.25)	4(0.25)	3(0.00)	3(0.00)	1.00	0.02	3	3
3(0.17)	1(0.33)	3(0.00)	3(0.00)	1.00	0.02	3	3
4(0.17)	1(0.25)	3(0.33)	3(0.00)	1.00	0.02	3	3
0(0.10)	3(0.38)	2(0.10)	2(0.00)	0.60	0.02	5	3
0(0.00	3(0.24)	3(0.27)	5(0.00)	0.60	0.02	5	3
0(0.00)	4(0.00)	3(0.31)	3(0.25)	0.75	0.02	4	3
0(-0.08)	1(0.00)	3(0.42)	3(0.42)	0.75	0.02	4	3
6(0.67)	4(0.33)	4(0.00)	4(0.50)	1.00	0.02	2	2
7(0.67)	3(0.25)	4(0.00)	4(0.33)	1.00	0.02	2	2
5(0.50)	3(0.00)	4(0.25)	2(0.75)	1.00	0.02	2	2
3(0.40)	2(0.33)	2(0.00)	2(0.17)	0.67	0.02	3	2
8(0.17)	1(0.25)	3(0.00)	2(0.00)	0.67	0.02	3	2
4(0.17)	3(-0.08)	3(0.11)	3(0.00)	0.67	0.02	3	2
							42

42. Height of German and English sound
0. other
1. G & E: high
2. G & E: low
3. G & E: non-high & non-low
4. G: high, E: non-high & non-low
5. G: high, E: low
6. G: non-high & non-low, E: high
7. G: non-high & non-low, E: low
8. G: low, E: non-high & non-low
9. G: low, E: high

43. Tenseness of German and English vowel
0.
1. G & E: vowel tense
2. G & E: vowel non-tense
3. G: vowel tense, E: vowel non-tense
4. G: vowel non-tense; E: vowel tense
5. other

50. German and English vowel backness
0.
1. G & E: back vowel
2. G & E: non-back vowel
3. G: back vowel, E: non-back vowel
4. G: non-back vowel, E: back vowel
5. other

51. German and English vowel roundness
0.
1. G & E: round vowel
2. G & E: non-round vowel
3. G: round vowel, E: non-round vowel
4. G: non-round vowel, E: round vowel
5. other

A fragment of the dictionary of variables has been appended to Table 11 in order to make it possible to read the contents of the determinacy table included in its lines (the arguments of the determinacy). Thus, the first line of the table (indicated by a *) indicates that there is the determinacy:

“If

(1) the German sound is ‘high’ and the English sound ‘non–high and non–low’ (variable 42, value 4),
(2) the German sound is ‘vowel tense’ and the English sound ‘vowel non–tense’ (variable 43, value 3),
(3) the German and English sounds are both ‘non–back vowel’ (variable 50, value 2), and
(4) the German and English sounds are both ‘non–round vowel’ (variable 51, value 2),

Then

subject SF judges these sounds to be ‘different’.”

This determinacy has the Accuracy (I) I = 0.83 and the Completeness (C) C = 0.04.

The argument of this determinacy has four components ((1), (2), (3), and (4) above). The extent to which they are substantial (their I-deposit) is given in the parentheses on the first line of the table next to the codes designating the values of the variables.

The effectiveness of component (1) (variable 42, value 4) equals 0.33. This means that if component (1) is disregarded, the accuracy of the determinacy is lowered by a magnitude of 0.33, i.e. becomes equal to 0.83 - 0.33 = 0.50.

The effectiveness of component (2) (variable 43, value 3) equals 0.25. This means that if this component is deleted from the argument of the determinacy, the accuracy of the determinacy will be reduced by 0.25, i.e. becomes equal to 0.83 - 0.25 = 0.58.

From this it follows that subject SF, when differentiating sounds, is more sensitive to component (1), i.e. to the differentiation of sounds on the basis of the feature ‘height’, than to component (2), i.e. to the differentiation of sounds on the basis of the feature ‘tenseness’.

Component (3) (variable 50, value 2) is immaterial, i.e. it has an accuracy equal to null. If ‘non-backness’ is deleted, then the accuracy of the determinacy remains equal to 0.83.

Component (4) (variable 51, value 2), at 0.17, is substantial.

If the components are ordered according to their degree of importance, we obtain the following rank order:

TABLE 12
Rank order of perceptual components.

Rank	Component	I-deposit
1	(1)	0.33
2	(2)	0.25
3	(4)	0.17
4	(3)	0.00

On the basis of this example, we establish an important effect, namely, the importance of a given component in a determinacy depends upon the background of the other components against which it is viewed. The importance of each of the components in the argument of the determinacy just discussed (cf. the line marked by * in the above table of determinacies) is measured on the background of three other components. However, if any component is deleted, the importance of a remaining component undergoes a change.

For example, let us delete component (3). This is equivalent to excluding the column corresponding to variable 50 from the table of determinacies. If we do this, we obtain the determinacy Table 13.

The rows may be deciphered with the help of the same fragment of the dictionary of variables as the one introduced above. If we compare the lines marked * in Tables 11 and 13, we observe that the deletion of the insubstantial variable (insubstantial for the given determinacy) causes the magnitude of importance of one of the remaining variables to become redistributed. The component which was component (1) in the preceding determinacy becomes even more substantial, because the I-deposit rises from 0.33 to 0.40. If German and English 'backness' (variable 50) are not differentiated, then the role of the feature 'G: high, E: non-high and non-low' in the determinacy is strengthened, whereas components (2) and (4) do not change in importance.

The deletion of a component may make a property important which was unimportant prior to the deletion. Compare the lines of the determinacies in Tables 11 and 13 that are marked by #'s. In Table 11 the property variable 50, value 3 (G: back vowel, E: non-back vowel) in this line has I-deposit = 0, i.e. an insignificant role. The property variable 51, value 3 (G: round vowel, E: non-round vowel), with I-deposit = 0, is also insignificant. However, in Table 13 if the property variable 50, value 3 is deleted, then the property variable 51, value 3 has an I-deposit of 0.25, i.e. it becomes substantial, and the importance of the other two properties in the argument of the determinacy also rises.

This effect is related to the manner of interaction of the properties and features which enter as components into the arguments of a determinacy.

TABLE 13

Determinacy table 2.

9 Subject: SF, Sex: f, Age: 21, Eng: 9, G:1

Different

Y = 128

X						
42	43	51			X	XY
4(0.22)	1(0.04)	3(0.22)	0.67	0.05	9	6
*4(0.40)	3(0.25)	2(0.17)	0.83	0.04	6	5
4(0.22)	3(-0.07)	3(-0.11)	0.56	0.04	9	5
3(0.22)	2(0.17)	3(0.00)	0.67	0.03	6	4
3(0.55)	1(0.50)	3(0.50)	1.00	0.02	3	3
#4(0.50)	4(0.38)	3(0.25)	1.00	0.02	3	3
5(0.32)	3(0.00)	2(0.55)	0.75	0.02	4	3
6(0.75)	4(0.33)	4(0.56)	1.00	0.02	2	2
7(0.73)	3(0.25)	4(0.75)	1.00	0.02	2	2
6(0.50)	4(0.33)	3(0.56)	1.00	0.02	2	2
3(0.42)	2(0.33)	2(0.00)	0.67	0.02	3	2
8(0.35)	1(0.33)	2(0.17)	0.67	0.02	3	2

Interestingly, of all the methods of data processing it is only the DA which permits the indepth investigation of this important effect.

Determinacy Table 11 suggests that the system of objective phonological features does not permit a sufficiently complete description of the individual system of differentiations of subject SF. Of the 128 cases in which SF selected ‘different’, only 18 cases may be explained with the help of Table 11. Determinacies with low accuracy ($I < 0.5$) or unique cases are not included in Table 11. Such determinacies, as can be seen, are in the majority.

CONCLUSION

In very recent years much attention has been paid to the subject of individual differences in reading efficiency within the framework of componential analysis (Carr and Levy, 1990). The results are cognitive skill maps and profiles of individual differences in reading performance in which high correlations among component skills such as word recognition, context use, reading comprehensions, listening comprehensions, visual wordmatching, etc. correspond to close distances among the skills on the map.

In our opinion, however, the point of the study of individual differences is not the extent to which skills are correlated within the individual, but which binders (precisors) elevate the accuracies of which arguments in which individuals, and to which extent, i.e. the study of intra- and inter-individual determinacies. In the final analysis, what makes the reading of one individual different from that of another is not the descriptive correlation of modularized component skills, but the causal determinacies which underlie the describable correlations.

We therefore endorse a determinacy-analytic approach to the investigation of individual differences, not only individual differences in similarity perception, or even individual differences in reading, but individual differences in general. In fact, whenever semiotic systems are concerned – as in the linguistics, psychology, sociology, literature, etc. – there are no differences but differences that are individual, because the locus of all such differences (Luelsdorff, 1986) is nowhere else but the individual. In sum, we support the differential study of humans in their manifold differentiation.

Arnheim (1974, pp. 79–92) devotes a section of his classic study of art and visual perception to the subject of similarity and difference. According to the author, "Whereas subdivision is one of the prerequisites of sight, similarity can make things invisible like a pearl on a white forehead ... Similarity acts as a structural principle only together with separation, namely as a force of attraction among segregated things."

Central to Arnheim's understanding of comparison is the notion of a 'common base'. Features of percepts, such as shape, brightness, color, spatial location, movement, etc., permit grouping by similarity, but comparisons make sense only if they proceed from a common base. "Comparisons, connections, and separations will not be made between unrelated things." For Arnheim, in the final analysis, "Similarity is a prerequisite for the noticing of differences."

Among the parameters of visual similarity Arnheim discusses are shape, spatial orientation, brightness, size, location, direction, and pattern recognition 'from above' and 'from below'. In bottom-to-top processing we can apply the principle of similarity only between units, whereas in top-to-bottom processing the principle of similarity accounts for the overall organization of the pattern as well.

The notion of a common base for judgements of difference and the notion that this base be expressible in terms of a common set of parameters, with a common set of settings, seem, at first sight, to be reasonable enough. Since, however, the parameters and fixings an individual might have presented are matters of personal, individual experience – there are as many grammars as there are individuals, and these are constantly changing – we situate them in the individual, and not in any extra-individual norm, however the norms might be individually fixed.

In the present study, we carried the notion of 'similarity' several steps further. First, we established that individual variation in similarity judgements in oral reading was the 'rule', rather than the exception. Second, we established that group variation in similarity judgements in oral reading – other things being more or less equal – was also the 'rule', rather than the exception. The individual differences we attributed to differences in command of English, and the group differences to differences in group-focus on the subject matter itself. Where less experienced learners make more judgements of 'similar', more experienced learners make more judgements of 'different'. Therefore, the ever-present norm, individually represented, induces in Praguian terms, a 'structural dynamism' in the system, whereby judgements move from 'similar' to 'different'. This movement, which is inherent to the system under real-time processing and acquisition, moves from less 'dynamic complexity' to more 'dynamic complexity', in accord with the empirically motivated dictates of the Law of Complexity (Luelsdorff, 1986, 1990, 1991; Luelsdorff *et al.*, 1990). The dynamism is thus directed, at once pulled forward by the represented norm and pushed back by complexity. Greater differentiation is, in fact, greater complexity, with, other things being equal, more intense psycholinguistic sets on differences eventuating in greater differentiation. Third, we establish that the similarity judgements studied are themselves bound by phonological features, and by some features to a much greater extent than others, revealing hierarchies of similarity-binder importance. Interestingly, in this regard even a deleted deposit may raise the accuracy deposits of the arguments it binds. Consequently, binders having accuracy deposits of 0 must also be taken into account.

The above conclusions were made possible by determinacy analysis (DA) (Chesnokov and Luelsdorff, 1991). While other methods, such as simple frequency counts, are used to establish individual and group variation, determinacy analysis is the only method available for the quantification of accuracy, completeness, and the accuracy and completeness deposits of binders (precisors). Since such quantifications are essential to establishing the precise causes of similarity and related judgements, it is concluded that determinacy analysis is to be preferred over other methods for these and unrelated purposes.

The goal of this study is to elucidate the nature of individual differences in similarity judgements. Towards this end we employed the individual characteristics of sounds in widespread use in the standard literature, asking if these features are able to explain the subjective similarity judgements. However, we lay no claim to the description or explanation of the psychological reality of the individual while forming such judgements of identity, similarity, and difference. On the contrary, we do not think that the question of the psychological reality of linguistic representations can be meaningfully posed, let alone satisfactorily answered. However, it does make sense to try to construct the features which permit making the same distinctions as those made by language knower-users. This is the problem we are trying to solve by using the objective characteristics of sounds. During the course of this search we came to the conclusion that the system of objective features is not the best of all possible systems. Evidently, there are other systems which permit more adequate description and explanation of judgements of sound similarity and differences in oral reading.

REFERENCES

Arnheim, R.: 1974, *Art and Visual Perception: A Psychology of the Creative Eye*, University of California Press, Berkeley.

Caramazza, A. and Hillis, A. E.: 1991, 'Modularity: A perspective from the analysis of acquired dyslexia and dysgraphia', in R. Malatesha Joshi (ed.), *Written Language Disorders*, Kluwer Academic Publishers, Dordrecht, pp. 71–84.

Caramazza, A. and Miceli, G.: 1991, 'The structure of graphemic representation', *Cognition* **37**, 243–297.

Carr, T. A. and Levy, B. A.: 1990, *Reading and Its Development: Component Skills Approaches*, Academic Press, London.

Chesnokov, S. V. and Luelsdorff, P. A.: 1991, 'Determinacy analysis and theoretical orthography', *Theoretical Linguistics* **17**, 231–262.

Chomsky, N.: 1981, *Lectures on Government and Binding*, Foris, Dordrecht.

Luelsdorff, P. A.: 1986, *Constraints on Error Variables in Grammar: Bilingual Misspelling Orthographies*, John Benjamins, Amsterdam.

Luelsdorff, P. A.: 1990, 'Orthographic complexity and orthography acquisition', in M. A. K. Halliday, J. Gibbons and H. Nicholas (eds.), *Learning, Keeping, and Using Language*, John Benjamins, Amsterdam, pp. 353–378.

Luelsdorff, P. A.: 1991, *Developmental Orthography*, John Benjamins, Amsterdam.

Luelsdorff, P. A. and Eyland, E. A.: 1991, 'A psycholinguistic model of the bilingual speller', in R. M. Joshi (ed.), *Written Language Disorders*, Kluwer Academic Publishers, Dordrecht, pp. 165–190.

Luelsdorff, P. A., Schötz, A. and Bergmann, C.: 1993, *Semiotic Complexity and Language Acquisition*, L.A.U.D., Series A, Universität Hamburg.

Miceli, G.: 1991, 'Across-patient variability: Some mechanisms underlying nonlexical spelling errors', in R. M. Joshi (ed.), *Written Language Disorders*, Kluwer Academic Publishers, Dordrecht, pp. 85–104.

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