NEUROPSYCHOLOGICAL DEFICITS IN ADULTS WITH DYSLEXIA

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The extensive literature attests to the wide range of neuropsychological deficits to be found in children whose reading and writing achievement are substantially less than expected for their mental age (here referred to as dyslexic). Their performance on tests of oral language ability is often impaired (Lawson and Inglis 1985), and it is generally held that this is because dyslexia is a language-based disorder (Vellutino 1979), or because a language-based dyslexia subtype is the most prevalent (Kinsbourne and Warrington 1963). However, it is unclear which, if any, of these impaired test performances reflect the same impairment in mental operations as those underlying the difficulty in learning to read, and which are coincidental accompaniments (*e.g.* Fein *et al.* 1988). Light might be cast on this issue by studying a population that to date has not been documented neuropsychologically, namely dyslexic adults.

Dyslexia often continues into the adult years, and numerous variables that characterize adults with dyslexia have been reported (see Aaron 1982, Miles 1986, Spreen 1989 for reviews). However, their undetermined neuropsychological status leaves scope for several contrasting predictions, depending on alternative models of the brain basis of dyslexia and of its response to remedial education.

Neuropsychological predictions

We organize our predictions around five hypothetical models.

MODEL I. The problem in learning to read is specific and unrelated to the accompanying neuropsychological deficits. The latter might reflect more transitory, coincidental immaturities of brain development. If so, dyslexic adults should have few accompanying neuropsychological deficits and the degree of their reading retardation and neuropsychological impairment should be relatively uncorrelated.

MODEL II. Even though the deficient mental operation in dyslexia might be independent of general language skills, the effect of impaired reading over the years will cumulatively induce inferior performance on a wide range of language tests (Bertelson 1986). If so, dyslexic adults should have a plenitude of deficiencies on language testing, and these might correlate highly with the severity of the reading problem. But they should not be deficient on tests that are unrelated to language experience, for example temporal order judgment and neuromotor tasks.

MODEL III. The dyslexia is due to transient neurological immaturity, and residual reading problems derive not from a continuing impaired brain basis for learning to read, but from the loss of

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instruction, compounded by expectation of failure that the difficult childhood years might have engendered (Denckla 1977, Stanovich 1980). If so, the severity of the reading difficulty and of neuropsychological impairments should not be correlated in adults.

MODEL IV. The dyslexia is due to a specific neuropsychological deficit that can also be identified by neuropsychological tests not involving reading (Kinsbourne and Warrington 1963). If so, a dyslexic adult should manifest specific neuropsychological deficits (for instance in component verbal skills) that are integral to the reading difficulty and closely related to it statistically. Coincidental deficits should be absent or only loosely related to the severity of the reading impairment by the time adulthood is reached.

MODEL V. Dyslexia severe enough to continue into the adult years is likely to be based on extensive cerebral impairment (Benton 1975). If so, it should be accompanied by a wide range of highly correlated neuropsychological deficits, beyond those which tap processes that underlie the reading problem itself. The correlations would be based on anatomical propinquity, not functional interrelationship.

In order to address these questions, we developed a neuropsychological test battery. A retest on each instrument evaluates the stability of the measure in question, with a view to its future usefulness as a measure of response to therapeutic efforts. A neuromotor battery was also included.

Adults recovered from dyslexia

In contrast to *severe dyslexia,* it is unclear whether adults *'recovered from dyslexia'* improved because they were better taught, had suffered from a less severe impairment, or had spontaneously matured. If they were better taught, they should differ little neuropsychologically from those with severe dyslexia, particularly in temporal order and neuromotor task performances, which presumably are unaffected by reading instruction. If they had matured neurologically, they would be likely to have few neuropsychological deficits. If their reading difficulty differed qualitatively from that of those with severe dyslexia, this might become apparent from history or from the present testing.

Neuromotor predictors

'Soft signs' of neuromotor immaturity have been noted repeatedly in children (*e.g.* Peters *et al.* 1975) and adolescents (Byring and Pulliainen 1984) with selective reading disability. These soft signs predict reading outcome (O'Connor and Spreen 1988). Although signs such as mirror and overflow movements usually recede as children grow older (*e.g.* Connolly and Stratton 1968), they can still be detected in adolescence (Shafer *et al.* 1986). However, no information is available on whether and in what forms these signs persist into the adult years. The same developmental pattern applies to speed of movement, which in preschool children is known to correlate positively with verbal fluency (Rudel 1985) and vocabulary (Annett 1973). If neuromotor disabilities persist into adulthood, high correlation between their severity and the severity of reading retardation in adults would support a persisting organic basis for the reading problems. If adults largely recovered from dyslexia remain as motor-disabled as those who are still severely dyslexic, this would suggest that reading recovery is due to educational variables. If dyslexic adults who have learned to read also have recovered from neuromotor difficulties, their brains must have matured in a more general sense.

Measures of reading ability

In order to apply the Finucci *et al.* (1984) criteria for adult dyslexia, we administered the Gray Oral Reading Test (GORT), from which can be derived measures of oral reading and comprehension, and the Wide Range Achievement Test (WRAT), which evaluates single-word reading and spelling. The resulting scores were entered into empirically derived regression equations that predict expected achievement. Deviation scores were determined by substracting observed scores from expected scores and dividing by standard errors of prediction. Negative deviation scores of more than 2·0 define dyslexia.

TABLE I
Sample characteristics

*Variable**	*Severe dyslexic (N=23)* Mean	(SD)	*Recovered dyslexic (N=11)* Mean	(SD)	*Control (N=21)* Mean	(SD)	*F(2, 52)*	*p*
VIQ	110·2	(16·2)	110·9	(9·7)	115·4	(15·7)	0·74	NS
PIQ	109·1	(15·7)	112·1	(17·4)	107·4	(12·1)	0·37	NS
FSIQ	110·8	(15·5)	112·5	(10·2)	112·7	(13·0)	0·12	NS
Age	29·3	(8·8)	23·9	(5·5)	26·5	(7·7)	1·93	NS
Education	13·7	(2·0)	14·3	(1·0)	14·4	(1·4)	1·03	NS
Social index	3·1	(0·9)	3·2	(0·6)	3·1	(0·7)	0·04	NS

*VIQ = verbal IQ; PIQ = performance IQ; FSIQ = full-scale IQ.

Auditory and visual dyslexia subtypes were identified by the Boder Test of Reading and Spelling Patterns (Boder and Jarrico 1982, and discussion by Kinsbourne 1984). The reading section of the Boder test consists of 13 graded 20-word lists (from preschool to adult levels). Half the words in each list are phonetic and half non-phonetic. Each word is presented by flash (one second) and then untimed (10 seconds). Based on performance on the reading test, two individual spelling lists were prepared; one of 10 known words, to determine whether the person could spell correctly those words s/he could read on sight, and one of 10 unknown words for which the person tried to write good phonetic equivalents. This indicates phonetic skills in spelling.

In addition, the Wechsler Adult Intelligence Scale-Revised (WAIS-R) was administered.

Subjects

Our experimental group comprised 23 adults with dyslexia of considerable severity, all meeting Finucci criteria. 16 of these were referred from two adult remedial reading programs. Our control group consisted of 21 normally reading adults, the groups being matched for age, sex distribution, Wechsler IQ and educational and occupational status. A contrast group of 11 adults was also included, who had a childhood history of dyslexia and reading remediation, but did not now meet Finucci criteria for dyslexia (Table I).

Hand preference was measured by the Edinburgh Handedness Questionnaire (Oldfield 1971), but was not controlled. The person indicates the writing hand and posture (inverted or non-inverted), and indicates hand preference (right, left, either) for five additional activities (hold toothbrush, throw ball at target, hammer, draw, cut with scissors). Non-right-handers comprised 16 per cent of the experimental group, 36 per cent of the contrast group and 19 per cent of the control group.

By Boder categorization, five of the adults with severe dyslexia were dysphonetic, one was dyseidetic, five were mixed and two were non-specific. Eight fell into Boder's 'undetermined' group, with relatively good reading but poor spelling of sight words. According to Boder, these are usually 'remediated dyslexics'.

Method

Language tests

Language tests were chosen to assess a spectrum of language subskills, including naming (Boston Naming Test), verbal free recall (California Verbal Learning Test) and paired associate learning (CPALT), as well as fluency in naming (RAN), and in word generation, by initial letter and by category (Word Fluency Tests). Previous studies have found dyslexic children to be deficient in various combinations of these and similar measures (Vellutino 1979).

Non-verbal cognitive tests

We administered two tests of temporal order judgment, auditory and visual. It has been suggested that some aspect of temporal processing underlies left-

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hemisphere specialization for language function (Carmon and Nachshon 1971). Efron (1963), Swisher and Hirsh (1972) and Ilmberger (1984) found individuals with acquired aphasia to be deficient in temporal order judgment, particularly in the auditory area. Lowe and Campbell (1965), Poppen *et al.* (1969) and Tallal and Stark (1982) found both auditory and visual temporal order judgment to be impaired in language-disordered children. A further purpose in choosing these tasks was that they appear to measure skills unrelated to anything that the subjects would have specifically practised in their everyday life.

As a non-verbal reference task on which unimpaired performance was predicted (Liberman *et al.* 1982), a nonsense shape memory task (Sackeim *et al.* 1986) was also administered.

Neuromotor tests

The battery developed by Denckla (1974, 1979) was used, as well as the Purdue grooved pegboard test. Tests for finger agnosia were also given, according to Kinsbourne and Warrington (1963): these were negative in all cases, and are not considered further.

Neuropsychological tests

RAPID AUTOMATIC NAMING TEST (RAN) (OBJECT AND COLOR SUBTESTS)

The RAN measures fluency in naming (Denckla and Rudel 1976). Each subtest is displayed on an 11 × 14″ chart containing a matrix of 50 randomly arranged stimuli, namely selections of five familiar pictured objects and five colors, respectively. The total naming latency for each matrix and all errors is recorded.

The object and color rather than the letter or number RAN subtests were chosen to avoid confounding the results with differential familiarity and/or reactions to emotionally charged material between groups.

TEST OF VERBAL FLUENCY: (FAS AND CATEGORIES)

The FAS requires the person to name, in 60 seconds each, words all beginning with F, A and S as quickly as s/he can, excluding proper nouns, numbers and the same word with a different suffix. In the Category Test, 60 seconds are available for naming as many fruits and vegetables as possible. According to Lezak (1983), FAS is most difficult for those who cannot devise a strategy to guide their search for words. Categories provide some of the structure for doing so.

BOSTON NAMING TEST

Sixty line-drawings are presented in descending order of familiarity. When a person is unable to name a drawing, s/he is given a stimulus cue; if still unable, a phonemic cue (Goodglass and Kaplan 1972).

CALIFORNIA VERBAL LEARNING TEST (CVLT)

The CVLT measures verbal memory, subdivided into immediate verbal memory, short-delay recall, long-delay recall and recognition. The examiner reads a list of 16 words at the rate of one word per second, five times. After each presentation, the person repeats as many words as s/he can remember, in any order (immediate verbal memory span). The examiner then presents a different list of 16 words, followed by an immediate memory test for this second list. Immediately after, the person is tested for free and cued recall of the original list items. A second recall test is given after a 20-minute interval. Finally, a recognition test is given.

CONTINUOUS PAIRED ASSOCIATE LEARNING TEST (CPALT)

The CPALT is a specifically designed, computerized, paired associate learning task. It measures the ability to retain associations between three-consonant groupings (stimuli) and numbers (responses). After a practice session, the person is shown each letter-number combination on a CRT for eight seconds, and is allowed five seconds to respond. Dependent variables are the total number of correct responses and mean list length (the average number of consecutive correct responses). Variability of mean list length across trials is also measured across the half-hour duration of the procedure.

TEMPORAL ORDER THRESHOLD (VISUAL AND AUDITORY)

These tasks, developed in our laboratory,

TABLE II
Group means for educational battery

Variable	Severe dyslexic (N=23) Mean	(SD)	Recovered dyslexic (N=11) Mean	(SD)	Control (N=21) Mean	(SD)	F(2, 52)	p
Gray Oral Reading (grade level)	6·0	(3·1)	11·3	(1·4)	12·0	(0·0)	48·87	<0·00001
WRAT Reading (raw score)	47·8	(14·2)	67·3	(8·1)	74·9	(8·4)	33·57	<0·00001
WRAT Spelling (raw score)	18·2	(8·7)	32·3	(5·9)	38·7	(6·5)	43·37	<0·00001
Boder Reading (quotient)	85·9	(20·3)	108·4	(8·5)	112·4	(2·8)	22·24	<0·0001

call for temporal resolution of two successive stimuli. On the visual task, the person views a sequence of two 3ms light flashes, one in each hemifield, in either a left-right or a right-left order. Testing begins at an interstimulus interval of 20ms, with 20ms increments until a 90 per cent criterion of order judgment accuracy is attained. The auditory task is similar, except that the person determines the left-right directional order of two 1ms clicking sounds delivered through stereo headphones connected to the TRS-80, also by ascending method of limits.

THE NONSENSE-SHAPE LEARNING TASK
On each trial of this measure of visual non-verbal memory (Sackeim *et al.* 1986) four stimulus cards are shown successively. Each card displays an irregular geometric shape. The person then picks the four target stimuli from a sequence of nonsense shapes.

DENCKLA NEUROMOTOR TASKS
The Denckla (1974) Neuromotor Battery includes five timed tasks, each involving 20 repetitive movements: (1) index-thumb finger-tapping; (2) sequential finger-tapping—five successive oppositions to the thumb of index, middle, ring and little finger; (3) prosupinations—alternating forearm pronation and supination; (4) toe-tapping—repetitive taps of the forefoot with the heel on the floor; and (5) heel-toe alternations—alternating heel-toe taps.

PURDUE PEGBOARD TEST
This timed test measures manual dexterity and motor co-ordination (Tiffin 1968). Ridged metal pegs are manoeuvred into slotted holes on a small wooden board, using the preferred hand, the non-preferred hand and then both hands.

Results

One-way analyses of variance were followed by specific contrasts between groups when over-all differences were significant. None of the group comparisons involving demographic variables (age, education, social index) and full-scale IQ was significant (see Table I). Thus the groups are considered to be adequately matched for these variables.

Table II presents the group means on the reading and spelling diagnostic tests. Comparison of the severe and control groups revealed significant differences in the GORT grade level, WRAT reading raw score, WRAT spelling raw score and Boder reading quotient. The recovered group differed significantly from the control group in the GORT grade level and the WRAT reading and spelling tests, and differed significantly from the severe group in the GORT, WRAT reading test, WRAT spelling test and the Boder reading quotient.

The test scores were converted to standard (z) scores and the mean standard scores for each group are shown in Figure 1. Contrary to the finding of Tarnopol and Tarnopol (1976) in adolescents, the dyslexic adults were about equally retarded in reading and spelling.

The standard score profiles for the groups on the neuropsychological and neuromotor tests are presented in Table III.

TABLE III
Standard scores* (SD from control sample)

	Severe dyslexic	*Recovered dyslexic*
Psychometric tests		
WAIS-R VIQ	−0·33	−0·29
WAIS-R PIQ	+0·14	+0·39
WAIS-R FSIQ	−0·14	0·00
Gray Oral Reading—grade level	−5·95	−0·67
WRAT Reading—raw score	−3·22	−0·90
WRAT Spelling—raw score	−3·16	−0·99
Boder reading level	−9·32	−1·42
Neuropsychological tests		
Boston Naming	−0·41	−0·10
Word Fluency—FAS	−0·96	−0·79
Word Fluency—Categories	−0·55	−1·05
RAN Objects	−2·27	−1·20
RAN Colors	−1·69	−0·98
Nonsense Shape Memory	−0·43	−0·16
CPALT	−1·17	−0·69
Temporal Order—Visual	−1·24	−0·79
Temporal Order—Auditory	−0·91	−0·46
CVLT Trial 1	−0·67	−0·18
CVLT Trial 5	−1·28	−0·36
CVLT Total Words	−1·15	−0·30
CVLT Short Delay	−0·88	−0·28
CVLT Long Delay	−0·86	−0·48
CVLT Recognition	−0·99	−0·43
*Neuromotor tasks***		
Index-thumb taps-right	−0·40	−0·01
Index-thumb taps-left	−0·63	−0·60
Sequential taps-right	−1·45	−0·25
Sequential taps-left	−0·73	+0·23
Prosupinations-right	−0·32	−0·55
Prosupinations-left	−0·87	0·00
Toe taps-right	−0·65	+0·65
Toe taps-left	−0·18	+0·75
Heel-toe-right	−1·34	−0·97
Heel-toe-left	−0·77	−0·80
Grooved pegboard-right	+0·06	+0·12
Grooved pegboard-left	+0·01	+0·13
Grooved pegboard-both	−0·19	−0·19

*z-scores are reported as negative if performance is poorer than that of controls.
**Right-handed adults only. Severe dyslexic N = 20, recovered dyslexic N = 7, control N = 18.

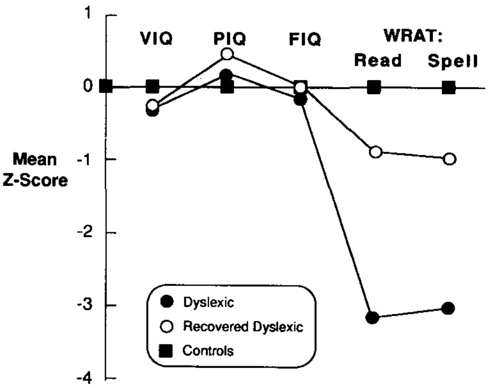

Fig. 1. Psychomotor test profiles.

All groups were tested on two separate occasions not less than seven days apart, to enable test-retest correlations for each of the tasks to be determined for the three groups (Table IV). All but one (test-retest reliability for the recovered dyslexic group on the word fluency test) were significant, and the mean correlation across tasks was significant for each of the three groups. The mean test-retest correlations (collapsed across task) were: severe dyslexic group $r = 0{\cdot}75$; recovered dyslexic group $r = 0{\cdot}80$; control group $r = 0{\cdot}74$.

In summary, the chosen tasks, both standard (except for Word Fluency—

TABLE IV
Test-retest reliability*

Cognitive Task	*Severe dyslexic*	*Recovered dyslexic*	*Control*
CPALT	0·87	0·82	0·88
RAN—Objects	0·81	0·85	0·83
RAN—Colors	0·64	0·84	0·88
Word Fluency—FAS	0·87	0·93	0·79
Word Fluency—Categories	0·52	0·38	0·43
Nonsense-shape Learning	0·77'	0·85	0·47

*All correlations except Word Fluency—Categories (recovered dyslexic) are significant beyond $p<0·01$.

TABLE V
Group comparisons

Variables	*Mean*	*(SD)*	*Mean*	*(SD)*	*t*	*df*	*p*
(A) Severe dyslexic vs. *control*							
	Severe dyslexia		*Control*				
Gray Oral Reading (grade level)	6·0	(3·1)	12·0	(0·0)	8·71	42	<0·0001
WRAT Reading (raw score)	47·8	(14·2)	74·9	(8·4)	7·59	42	<0·0001
WRAT Spelling (raw score)	18·2	(8·7)	38·7	(6·5)	8·78	42	<0·0001
Boder Reading (quotient)	85·9	(20·3)	112·4	(2·8)	5·91	42	<0·0001
CPALT	162·7	(76·5)	275·1	(91·3)	4·44	42	<0·001
RAN—Objects	48·2	(8·3)	35·0	(5·9)	6·03	42	<0·0001
RAN—Colors	36·4	(7·0)	27·2	(5·3)	4·84	42	<0·0001
Temporal Order—Visual	58·7	(25·8)	37·0	(17·5)	3·17	41	<0·005
Temporal Order—Auditory	67·4	(25·4)	46·8	(22·6)	2·74	40	<0·01
FAS—Initial Letters	35·4	(10·9)	44·4	(13·3)	2·46	42	<0·01
CVLT Trial 5	11·5	(2·6)	13·6	(1·7)	3·23	41	<0·005
CVLT Total Words	49·3	(11·0)	57·4	(7·0)	2·85	41	<0·01
CVLT Recognition	14·4	(1·1)	15·3	(0·9)	2·93	41	<0·01
Sequential taps right	7·7	(1·9)	6·0	(1·2)	3·40	36	<0·005
Heel-toe right	7·2	(1·4)	5·8	(1·0)	3·33	36	<0·005
(B) Severe dyslexic vs. *recovered dyslexic*							
	Severe dyslexic		*Recovered*				
Gray Oral Reading (grade level)	6·0	(3·1)	11·3	(1·4)	5·32	32	<0·0001
WRAT Reading (raw score)	47·8	(14·2)	67·3	(8·1)	4·21	32	<0·0005
WRAT Spelling (raw score)	18·2	(8·7)	32·3	(5·9)	4·84	32	<0·0001
Boder Reading (quotient)	85·9	(20·3)	108·4	(8·5)	3·50	32	<0·001
RAN—Objects	48·2	(8·3)	41·5	(6·9)	2·32	32	<0·05
(C) Recovered dyslexic vs. *control*							
	Recovered		*Control*				
Gray Oral Reading (grade level)	11·3	(1·4)	12·0	(0·0)	2·24	30	<0·05
WRAT Reading (raw score)	67·3	(8·1)	74·9	(8·4)	2·45	30	<0·05
WRAT Spelling (raw score)	32·3	(5·9)	38·7	(6·5)	2·73	30	<0·01
RAN—Objects	41·5	(6·9)	35·0	(5·9)	2·80	30	<0·01
RAN—Colors	32·0	(4·1)	27·2	(5·3)	2·60	30	<0·01
Word Fluency Categories	17·7	(2·1)	20·9	(2·7)	3·41	30	<0·005

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TABLE VI
Correlations of reading and spelling achievement*

Task	*Gray Oral Reading (raw score)*	*WRAT Spelling (raw score)*
CPALT	0·50	0·59
RAN—Objects	−0·65	−0·63
RAN—Colors	−0·62	−0·52
Temporal Order—Visual	−0·39	−0·41
Temporal Order—Auditory	−0·42	−0·44
CVLT—Trial 5	NS	0·38
CVLT—Total Words	NS	0·36
Sequential taps right**	−0·46	−0·45
Heel-toe right**	−0·47	−0·45

*All correlations are significant beyond $p<0·01$. **Right-handed adults only.

Categories) and those specifically developed for this study, were highly reliable, and comparably so for all three groups.

Group comparisons

SEVERE DYSLEXIC *vs.* CONTROL

These groups differed significantly in all tests except Nonsense-shape Learning, Boston Naming and some CVLT subtests (the dyslexic group scoring lower in every case) (Table V). Confining analysis to right-handed persons, the severe dyslexic group was significantly inferior to the control group in sequential finger-tapping on the right side and heel-toe alternations on the right side.

SEVERE DYSLEXIC *vs.* RECOVERED DYSLEXIC

These groups differed significantly only on RAN (objects). The neuromotor tasks yielded no significant differences. On all tests that discriminated severe from control groups, recovered performance level was intermediate.

RECOVERED DYSLEXIC *vs.* CONTROL

These groups differed significantly only in the two RAN tests and the FAS Categories test. The neuromotor tasks yielded no significant differences. On stepwise discriminant analysis, RAN (objects) was the most discriminating, correctly classifying 79 per cent of the dyslexic and control groups. The non-language variables, auditory and visual temporal order judgments, correlated 0·30 and 0·51, respectively, with RAN (objects).

As expected, the nonsense-shape memory test (assumed to indicate right posterior hemisphere skills) did not discriminate between groups. The dyslexic group did not perform better than the controls, however, as has sometimes been reported (Symmes 1972, Gordon 1980).

Correlations

Product moment correlations (with effects of VIQ, PIQ and FSIQ removed) were computed between the dependent variables of interest. The following were significant beyond the 0·01 level of confidence (Table VI).

Performance on the two RAN tests correlated highly with both reading and spelling achievement, as is to be expected from the relevant specific contrasts. The other significant cognitive correlate of both achievement measures was the paired associate learning test. More surprising was the strong relationship between both educational variables and the right-sided sequential finger apposition test and the right heel-toe test. These two simple, repetitive movements were stronger correlates than the numerous language variables measured in this study, as well as the two temporal order tests. In view of this finding, it can no longer be assumed that any highly correlated or discriminating variable necessarily indicates an underlying cognitive operation that reading or spelling both draw upon. Instead, many 'left hemisphere' performances may reflect, to a variable extent, the functional integrity of that hemisphere as a whole. The ability to program right-sided rapidly alternating movements controlled by the left hemisphere, in the absence of lower-level motor deficit, may be a relatively sensitive index of the hemisphere's integrity.

Correlations between cognitive measures were generally high, as might be expected from their relative power in discriminating between experimental groups. Among them, the visual temporal order measure was a relatively powerful correlate. Yet it appears that difficulties in rendering temporal order judgments are not specific to dyslexia or language disorder (Ludlow *et al.* 1983).

Discussion

The generality of any clinical sample is constrained by the way in which it was acquired. It is more difficult to find dyslexic adults than dyslexic children, all of whom are in school and under continuous scrutiny with respect to their reading skills. Our group may have over-represented dyslexic adults who continued to make an effort to learn to read beyond school-age. They may differ somewhat from those who have abandoned such efforts and who did not feature in our sample. It is not clear, however, whether this would make a difference to the neuropsychology of their condition.

Applied to our sample with severe dyslexia (meeting Finucci criteria) and 'recovered dyslexics', our neuropsychological and neuromotor test battery yielded reliable correlates of the degree of reading retardation across a wide range of reading ability. The battery was found to be sensitive in detecting impairment in diverse behavioral functions. It revealed that adult dyslexia coexists with several neuro-cognitive deficiencies, other than those involving reading. They include:

(1) Verbal learning and memory deficits, as elicited by the Continuous Paired Associate Learning Test and the California Verbal Learning Test. Those with severe dyslexia are impaired in verbal acquisition and retention ability. Vellutino *et al.* (1975) reported deficient learning by dyslexic children of associations between trigrams and word responses. Our data extend this effect to adults and to digit responses (typed rather than spoken).

(2) Deficient automatization of language subprocesses, as assessed by the Word Fluency and the RAN tests. These tasks index the extent to which relatively low-level cognitive processes become automatic. Word fluency deficit was documented in dyslexic children by Felton and Wood (1989). Those authors, like ourselves with adults, found the Boston Naming Test not to discriminate dyslexia in children.

(3) Temporal order judgment deficits. The temporal order judgment tasks were as useful for discrminating groups as were the more discriminating among the verbal tasks. Dyslexic adults were deficient in both the auditory and visual fields; their scores on these tests correlated highly with those on the best discriminating task, RAN (objects). Temporal order judgments involved resolution of sequential inputs cross-hemispherically.

(4) Deficient dexterity in right-sided sequential finger and foot movements. This answers the question of Rudel (1985, p.50) of whether deficits on motor tasks are 'symptomatic of dyslexia only before age nine or 10'. Contrary to Leslie and colleagues' (1985) findings in children, there was no significant deficit on the Purdue Pegboard Test. Their conclusion that dyslexic children have disproportionate difficulty with intermanual motor integration is not supported by our data (see also Hermann *et al.* 1986). This is consistent with the finding that repetitive movements (rather than alternating) are impaired in dyslexic children (Rudel 1985). But Rudel did not find a differential right-sided impairment in her grade-school sample. In general, the neuromotor deficits we found were more substantial than those in previous studies (*e.g.* Badian and Wolff 1977), or when attention deficit disorder rather than dyslexia is considered (Denckla and Rudel 1978). Perhaps this is because neuromotor impairment characterizes those with the most severe dyslexia, and they are the most likely to be found in an adult dyslexic sample.

The absence of evidence of finger

agnosia (and other elements of congenital Gerstmann syndrome; Kinsbourne and Warrington 1963) is consistent with the impression that this subtype tends to remit.

This first attempt to characterize adult dyslexia neuropsychologically enables several conclusions to be drawn. Dyslexic adults are impaired compared with controls on a range of neuropsychological tests not involving reading, and even on some motor tasks. The study also demonstrates that a severe brain-based neuropsychological syndrome that features dyslexia can persist into the adult years. The present data do more than simply corroborate that dyslexic children may continue to experience reading difficulty in adulthood. Neurocognitive immaturities might resolve, yet patients might continue to suffer from the after-effects of years of effectively missed instruction, and the resulting expectation of failure could prevent further effort. However, no such effect was reflected in our data. The host of associated neuropsychological and neuromotor deficits indicates continuing and perhaps permanent neurological impairment. Deficits in non-verbal domains cannot simply be secondary consequences of the deprivation of language experience that complicates severe reading retardation.

Impairments were evident on tasks that could be tapping mental operations that are also directly implicated in reading acquisition, such as indices of verbal fluency or verbal memory. But there were also impairments in non-verbal tasks, both sensory-visual and auditory temporal order judgments and rapid repetitive motor movements of right-sided (*i.e.* left hemisphere-controlled) limbs. The temptation to subdivide these into one subset that measures a hypothetical reading-related cerebral module, and another that represents miscellaneous associated deficits, should be resisted, because such a distinction lacks statistical support. Merely 'associated' deficits should be less tightly correlated with the severity of the reading difficulty, yet the temporal order and the motor deficits correlated relatively strongly. Any attempt to construe the full set of discriminating tests as tapping a unitarily conceived function that might be deficient in dyslexic people would have to arrive at an extremely broad formulation, such as 'sequencing' or automatization, which at best might characterize the role of the dominant hemisphere as a whole, and far transcends reading-related cognitive processes. In fact recent findings in the visual non-verbal domain (Lovegrove and Slaghuis 1989) suggest that even a general impairment of dominant hemisphere function might understate the breadth of deficits in dyslexia.

Investigators frequently assume that dyslexia is a selective or 'pure' deficit, hypothesize about its basis, administer tests for the implicated mental operation, and are content to demonstrate that a dyslexic sample does less well than a control sample on these tests. Our findings demonstrate that this approach is inadequate. Too many tasks discriminate, and do so powerfully, between the dyslexic and control groups. To validate a discriminating procedure as tapping a mental operation, deficiency of which renders it difficult to learn to read, one must demonstrate that the quality of reading performance reflects the supposed impairment (as, for instance, was attempted by Kinsbourne and Warrington (1963)). Numerous subsequent attempts to subtype by neuropsychological test profile, though often methodologically sophisticated, lack such validation, and none rules out the type of association-without-causation that is suggested by our findings. The present sample was not large enough to lend itself to cluster analysis, but our results do not encourage such an effort. There is no indication of any subgrouping. A single variable, RAN (objects), discriminated with 79 per cent accuracy. It could be, of course, that although multiple subtypes exist, only one (the phonological?) persists into adulthood.

In terms of the subtyping of Boder and Jarrico (1982), almost all those with classifiable dyslexia were dysphonemic. Those who are mostly impaired in spelling escape Boder classification. With respect to severe dyslexia, our data generally discourage attempts at classification by association (*e.g.* Mattis *et al.* 1975, Denckla 1979). A diverse pattern of correlated neuropsychological deficits could reflect widespread left-hemisphere damage, without causal connection to the reading difficulty itself. A relative difficulty in activating left-hemisphere resources (Kinsbourne 1989) would yield a similar test profile. Why there is not right-hemisphere compensation for such deficits needs additional explanation (Satz 1990), since the ability of that hemisphere to support language functions within the normal range after early left brain-damage is well documented (*e.g.* Aram and Ekelman 1986).

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SUMMARY
Adults with severe dyslexia were compared with age-, sex-, IQ- and SES-matched controls on a neuropsychological and neuromotor test battery, and a contrast group who had recovered from dyslexia was also included. The severely dyslexic group was substantially impaired on tests of verbal fluency and learning, as well as on non-verbal temporal order judgements. These test scores were strong predictors of the degree of reading impairment, as was the rate of repetitive movement of the right hand and foot. The results suggest that adult dyslexia is not 'isolated', but is one expression of a widespread left-hemisphere dysfunction.

RÉSUMÉ
Déficits neuro-psychologiques chez les dyslexiques adultes
Des adultes présentant une dyslexie sévère ont été comparés à des contrôles appariés pour l'âge, le sexe, le QI et le milieu socio-culturel, à partir d'une batterie de tests neuro-psychologiques et neuro-moteurs, et un groupe contraste de dyslexiques guéris fut également inclus dans l'étude. Le groupe de dyslexie grave présentait une altération significative au test d'aisance verbale et d'apprentissage aussi bien qu'au test d'appréciation d'ordre temporel non-verbal. Ces scores de tests étaient de très bons prédicteurs du degré de troubles de la lecture, de même que les taux de mouvements répétitifs de la main et du pied droit. Ces résultats suggèrent que la dyslexie de l'adulte n'est pas "isolée" mais l'expression d'un trouble fonctionnel étendu du l'hémisphère gauche.

ZUSAMMENFASSUNG
Neuropsychologische Störungen bei erwachsenen Dyslektikern
Erwachsene mit schwerer Dyslexie wurden zusammen mit Kontrollen, die im Alter, Geschlecht, IQ und SES übereinstimmten, neuropsychologisch und neuromotorisch getestet und außerdem wurde noch eine Gruppe von geheilten Dyslektikern einbezogen. Die Patienten mit schwerer Dyslexie hatten beim Sprachfluß und-wissen, sowie bei der zeitlichen Abfolge erhebliche Störungen. Diese Testergebnisse lieferten eine eindeutige Prognose für den Grad der Leseschwäche, wie auch die Rate der repetitiven Bewegung der rechten Hand und des rechten Fußes. Die Befunde deuten darauf hin, daß die Dyslexie im Erwachsenenalter keine 'isolierte' Störung, sondern Ausdruck einer ausgedehnten Dysfunkton der linken Hemisphäre ist.

RESUMEN
Déficits neuropsicológicos en disléxicos adultos
Se compararon adultos con dislexia grave con controles comparativos según la edad, sexo, CI y SES aplicando una batería de tests neuropsicológicos y neuromotores; se incluyó también un grupo de contraste de disléxicos recuperados. El grupo con dislexia grave mostró alteraciones substanciales en los tests de fluidez verbal y de aprendizaje, así como en el juicio de órdenes temporales no verbales. Los puntajes de estos tests eran unos predictores del grado de alteración en la lectura, así como la frecuencia de movimientos repetitivos de la mano y pie derechos. Los resultados sugieren que la dislexia del adulto no es aislada, sino una expresión de una disfunción extensa del hemisferio izquierdo.

References
Aaron, P. G. (1982) 'The neuropsychology of developmental dyslexia.' *In* Malatesha, R. N., Aaron, P. G. (Eds.) *Reading Disorders: Varieties and Treatments.* New York: Academic Press.
Annett, M. (1973) 'Laterality of childhood hemiplegia and the growth of intelligence.' *Cortex,* **9**, 4–33.
Aram, D. M., Ekelman, B. L. (1986) 'Cognitive profiles of children with early onset of unilateral lesions.' *Developmental Neuropsychology,* **2**, 155–172.
Badian, N., Wolff, P. (1977) 'Manual asymmetries of motor sequencing in boys with reading disability.' *Cortex,* **13**, 343–349.
Benton, A. L. (1975) 'Developmental dyslexia: neurological aspects.' *Advances in Neurology,* **7**, 1–47.
Bertelson, P. (1986) 'The onset of literacy: liminal

remarks.' *Brain and Cognition,* **24,** 1–30.

Boder, E., Jarrico, S. (1982) *Boder Reading and Spelling Pattern Test: A Diagnostic Screening Test for Developmental Dyslexia.* New York: Grune & Stratton.

Byring, R., Pulliainen, V. (1984) 'Neurological and neuropsychological deficiencies in a group of older adolescents with dyslexia.' *Developmental Medicine and Child Neurology,* **26,** 765–773.

Carmon, A., Nachshon, I. (1971) 'Effect of unilateral brain damage on perception of temporal order.' *Cortex,* **7,** 410–418.

Connolly, K., Stratton, P. (1968) 'Developmental changes in associated movements.' *Developmental Medicine and Child Neurology,* **10,** 49–56.

Denckla, M. B. (1974) 'Development of motor-co-ordination in normal children.' *Developmental Medicine and Child Neurology,* **16,** 729–741.

— (1977) 'Minimal brain dysfunction and dyslexia: beyond diagnosis by exclusion.' *In* Blau, M.E., Rapin, I., Kinsbourne, M. (Eds.) *Topics in Child Neurology.* New York: Spectrum.

— (1979) 'Childhood learning disabilities.' *In* Heilman, K. M., Valenstein, E. (Eds.) *Clinical Neuropsychology.* New York: Oxford University Press.

— Rudel, R. G. (1976) 'Rapid "automatized" naming (RAN): dyslexia differentiated from other learning disabilities.' *Neuropsychologia,* **14,** 471–479.

— — (1978) 'Anomalies of motor development in hyperactive boys.' *Annals of Neurology,* **3,** 231–233.

Efron, R. (1963) 'Temporal perception, aphasia and deja vu.' *Brain,* **86,** 403–424.

Fein, G., Davenport, L., Yingling, C. D., Galin, D. (1988) 'Verbal and nonverbal memory deficits in pure dyslexia.' *Developmental Neuropsychology,* **4,** 181–197.

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

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

Goodglass, H., Kaplan, E. (1972) *The Assessment of Aphasia and Related Disorders.* Philadelphia: Lea & Febiger.

Gordon, H. W. (1980) 'Cognitive asymmetries in dyslexic families.' *Neuropsychologia,* **18,** 645–656.

Hermann, H. T., Sonnabend, N. L., Zeevi, Y. Y. (1986) 'Interhemispheric coordination is compromised in subjects with developmental dyslexia.' *Cortex,* **22,** 337–358.

Ilmberger, J. (1984) 'Dissociation of visual and auditory order thresholds after cerebral injury in man.' *Human Neurobiology,* **3,** 245–247.

Kinsbourne, M. (1984) 'The Boder Test of Reading-Spelling Patterns: a diagnostic screening test for subtypes of reading disability.' *Developmental Medicine and Child Neurology,* **26,** 263–265. *(Book review.)*

— (1989) 'Neuronatomy of dyxlexia.' *In* Bakker, D. J., van der Vlugt, H. (Eds.) *Learning Disabilities, Volume 1: Neuropsychological Correlates and Treatment.* Amsterdam: Swets & Zeitlinger.

— Warrington, E. K. (1963) 'Development factors in reading and writing backwardness.' *British Journal of Psychology,* **54,** 145–156.

Lawson, J. S., Inglis, J. (1985) 'Learning disabilities and intelligence test results: a model based on a principal components analysis of the WISC-R.' *British Journal of Psychology,* **76,** 35–48.

Leslie, S. C., Davidson, R. J., Bailey, O. B. (1985) 'Purdue pegboard performance of disabled and normal readers: unimanual versus bimanual differences.' *Brain and Language,* **24,** 359–369.

Lezak, M. (1983) *Neuropsychological Assessment, 2nd Edn.* New York: Oxford University Press.

Liberman, I. Y., Mann, V. A., Shankweiler, D., Werfelman, M. (1982) 'Children's memory for recurring linguistic and nonlinguistic material in relation to reading ability.' *Cortex,* **18,** 367–375.

Lovegrove, W., Slaghuis, W. (1989) 'How reliably are visual differences found in dyslexia?' *Irish Journal of Psychology,* **10,** 542–550.

Lowe, A. D., Campbell, R. A. (1965) 'Temporal discrimination in aphasics and normal children.' *Journal of Speech and Hearing Research,* **8,** 313–314.

Ludlow, C. L., Cudahy, E. A., Bassich, C., Brown, G. L. (1983) 'Auditory processing skills of hyperactive, language-impaired and reading-disabled boys.' *In* Lasky, E. Z., Katz, J. (Eds.) *Central Auditory Processing Disorders: Problems of Speech, Language and Learning.* University Park, MD: University Park Press.

Mattis, S., French, J. H., Rapin, I. (1975) 'Dyslexia in children and young adults: three independent neuropsychological syndromes.' *Developmental Medicine and Child Neurology,* **17,** 150–163.

Miles, T. R. (1986) 'On the persistence of dyslexic difficulties into adulthood.' *In* Pavlidis, G. Th., Fisher, D. F. (Eds.) *Dyslexia: Neuropsychology and Treatment.* New York: Wiley.

O'Connor, S. C., Spreen, O. (1988) 'The relationship between parents' socioeconomic status and education level, and adult occupational and educational achievement of children with learning disability.' *Journal of Learning Disabilities,* **21,** 148–153.

Oldfield, R. C. (1971) 'The assessment and analysis of handedness: the Edinburgh Inventory.' *Neuropsychologia,* **9,** 97–113.

Peters, J. E., Romine, J. S., Dykman, R. A. (1975) 'A special neurological examination of children with learning disabilities.' *Developmental Medicine and Child Neurology,* **17,** 63–78.

Poppen, R., Stark, J., Eisenson, J., Forrest, T., Werhein, G. (1969) 'Visual sequencing performance of aphasic children.' *Journal of Speech and Hearing Research,* **12,** 283–300.

Rudel, R. G. (1985) 'The definition of dyslexia: language and motor deficits.' *In* Duffy, F. H., Geschwind, N. (Eds.) *Dyslexia.* Boston: Little, Brown.

Sackeim, H. A., Portnoy, S., Neeley, P., Stief, B. L., Decina, P., Malitz, S. (1986) 'Cognitive consequences of low-dosage electroconvulsive therapy.' *Annals of New York Academy of Sciences,* **462,** 326–340.

Satz, P. (1990) 'Developmental dyslexia: an etiological reformulation.' *In* Pavlidis, G. Th. (Ed.) *Perspective on Dyslexia, Vol. I,* Chichester, Sussex: Wiley.

Shafer, S. Q., Stokman, C. J., Shaffer, D., Ng, S. K.-C., O'Connor, P. A., Schonfeld, I. S. (1986) 'Ten-year consistency in neurological test performance of children without focal neurological deficit.' *Developmental Medicine and Child Neurology,* **28,** 417–427.

Spreen, O. (1989) 'Long-term sequelae of learning disability: a review of outcome studies.' *In* Bakker, D. J., van der Vlugt, H. (Eds.) *Learning Disabilities, Vol. I: Neurological Correlates and Treatment.* Amsterdam: Swets & Zeitlinger.

Stanovich, K. (1980) 'Toward an interactive compensatory model of individual differences in the acquisition of literacy.' *Reading Research*

Quarterly, **19,** 278–303.
Swisher, L., Hirsh, I. J. (1972) 'Brain damage and the ordering of two temporally successive stimuli.' *Neurosychologia,* **10,** 137–151.
Symmes, J. S. (1972) 'Deficit models, spatial visualization and reading disability.' *Bulletin of the Orton Society,* **22,** 54–68.
Tallal, P., Stark, R. E. (1982) 'Perceptual/motor profiles of reading impaired children with or without concomitant oral language deficits.' *Annals of Dyslexia,* **32,** 163–176.
Tarnopol, L., Tarnopol, M. (1976) *Reading Disabilities: An International Perspective.* Baltimore: University Park Press.
Tiffin, S. (1968) *The Purdue Pegboard.* Chicago: Research Associates.
Vellutino, F. R. (1979) *Dyslexia, Theory and Research.* Cambridge, MA: MIT Press.
— Steger, J. A., Harding, C. J., Phillips, F. (1975) 'Verbal *vs.* non-verbal paired-associates learning in poor and normal readers. *Neuropsychologia,* **13,** 75–82.