DISCRIMINATION OF NORMAL AND AT-RISK PRESCHOOL CHILDREN ON THE BASIS OF NEUROLOGICAL TESTS

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The value of the neurological examination in the study of children with mild cognitive dysfunction or with specific learning disabilities has long been a matter of dispute. Early observations of minor neurological abnormalities in such children (Prechtl and Stemmer 1962, Illingworth 1963, Gubbay *et al.* 1965, Rutter *et al.* 1966) were followed by reports that such signs may occur in children without cognitive disorders and, conversely, that their absence does not preclude learning problems (Schain 1970, Adams *et al.* 1974, Hart *et al.* 1974, Shaywitz *et al.* 1984).

Before neurological test items can be used meaningfully, the normal age-range for acquisition of the motor and sensory discrimination skills being tested must be known, and separately for boys and girls (Schain 1972, Werry 1972). Some norming has been carried out for school-age children (Peters *et al.* 1975, Gillberry *et al.* 1983, Rasmussen *et al.* 1983, Younes *et al.* 1983), but only a few neurological test items (*e.g.* finger localization) have been evaluated critically in the preschool age-group (Satz *et al.* 1976).

Another issue relates to the predictive value of preschool sensorimotor tests for later cognitive functioning, including language. Screening tests proposed for the early identification of children suspected of having learning difficulties have often contained a mixture of motor, sensory, language and other cognitive items (Schain 1972, Shaywitz *et al.* 1984, Whitmore and Bax 1986). This makes it very difficult to assess how simple motor and sensory functions, as tested by neurological examination, are related to cognitive function, as seen in standardized intelligence tests or school performance. Establishment of correlations between simple motor and sensory tests and later cognitive functions is of interest for our understanding of central nervous system maturation (Szatmari and Taylor 1984). It is particularly interesting to know whether, and to what extent, maturational lags are diffuse, affecting simple motor and sensory functions, as well as more complex cognitive abilities, including language. Such information also has practical importance, especially in the preschool years, since there is a persistent need for simple diagnostic tools to aid early identification of at-risk children. Longitudinal follow-up studies designed to evaluate the predictive value of neurological tests are not available.

We were recently able to carry out neurological evaluation of a large group of three- and five-year-olds. The children were either normal or 'at-risk' for learning difficulties, as identified by a screening interview conducted by the educational authorities. We were able to

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determine the normal range of performance at these ages and to identify those tests that significantly discriminate normal children from those at-risk. Two years later, the five-year-olds were also given psychological assessments. These provided data on the predictive value of the neurological examination. Our findings suggest that a small, easily performed, battery of neurological tests is useful in the early detection of children with learning difficulties.

Method

Subjects

All the children were drawn from Schaumburg, a middle-class suburban school district in the Chicago area, which was chosen to minimize the rôle of environmental stresses, especially poverty. The 'at-risk' children had been placed into special education classes at preschool and kindergarten because of suspected deficits in intellectual functioning. These children had been identified by the local public school system. None of the participants in the present study was involved in the selection process, and specific reasons for placement of individual children were not known to the experimenters.

SCREENING METHOD USED BY SCHOOL SYSTEM

All parents residing in the school district were encouraged to bring their children for a diagnostic interview after the child's third birthday. Groups of about four children were observed in an informal play setting by a team which included a speech pathologist, psychologist, nurse, social worker and classroom teacher. Decisions concerning the need for special education were made by the entire team, and were based on estimates of the child's language, social and motor skills. Mentally retarded children were excluded, as were children with major motor disorders, such as cerebral palsy. Hearing loss as a cause of language delay was excluded by audiometric screening. Although admittedly imprecise, this selection process made it possible for us to compare sensorimotor functioning in a group likely to have a high incidence of cognitive delays compared with a normal group.

The control children were drawn from the same socio-economic group and most lived in the same school district. The analysis of follow-up data did not rely on the initial grouping of children into at-risk and normal categories, since the comparisons of early neurological test findings with later IQ and class placements were independent of these groupings. The testers did not know whether children belonged to a control or at-risk group, except when testing was carried out in schools known not to contain special classes. Comparison of groups tested blindly versus those in which the tester might know the status of the child showed no significant differences.

TABLE I

Scores achieved on 24 items from neurological examination of Touwen and Prechtl (1970), using their graded scoring system*

		3-year-olds		*5-year-olds*	
		At Risk	*Normal*	*At Risk*	*Normal*
Males	Mean	19·32	17·59	11·23	6·38
	(SD)	(7·65)	(6·96)	(7·89)	(3·13)
	N	34	27	30	24
Females	Mean	15·69	14·52	8·45	6·73
	(SD)	(5·63)	(5·37)	(5·54)	(4·90)
	N	16	23	20	26

*There are significant differences between the normal and at-risk groups ($p<0·01$) and between boys and girls ($p<0·02$).

Construction of a simple sensorimotor (neurodevelopmental) preschool test

Initially, 50 normal and 50 at-risk three-year-old children (as defined above) and 50 normal and 50 at-risk five-year-old children were tested with 24 items from *The Neurological Examination of the Child with Minor Nervous Dysfunction* (Touwen and Prechtl 1970). The items included various cranial-nerve function tests, assessment of spontaneous gross and fine motor activity, assessment of involuntary movements, hand co-ordination, gait, tendon and plantar reflexes, and sensory discrimination. The graded scoring system described by Touwen and Prechtl was used.

The test results demonstrated some differentiation between normal and at-risk groups, especially for five-year-old males (Table I). However, this initial battery

TABLE II
Final set of neurological tasks with scoring criteria

Task	*Description*	*Passing performance*
Walk on toes	Walk across room on toes after task is demonstrated by tester	Walks on toes with both feet
Walk on heels	Walk across room on heels after task is demonstrated by tester	Walks on heels with both feet
Tandem gait forward	Walk heel to toe on a line marked by tape after demonstration by tester	Walks with sufficient balance to avoid stepping off line
Tandem gait backward	Walk heel to toe on tape line after demonstration by tester	Walks with sufficient balance to avoid stepping off line
Touch localization	Child is asked to close eyes and to point to or report where he is touched. The examiner touches, in turn, the dorsum of one hand, the other hand and both hands	Reports all stimuli correctly
Restless movements	Child sits on a chair with feet off the floor; hands in lap; he is asked to sit completely still for 1 minute (timed)	Child remains seated throughout the 1 minute test and is motionless for at least half the test period
Downward drift	Standing with outstretched pronated hands for 20 secs, eyes closed	No downward drift of either arm
Hand co-ordination	Child is asked to initiate rapid alternating supination and pronation of one hand at a time	Smooth supination-pronation for at least 3 cycles with each hand
Hopping	Child is asked (or shown) to hop on one foot	Able to hop on each foot
Alternate tapping	Child is asked to imitate 3 tapping tasks: (1) tap 5 times with right index finger (at a rate of about 2 taps/sec); (2) tap 5 times with left index finger; (3) tap alternately with left and right index finger for 4 cycles	Performs all 3 tasks
Complex tapping	Child is asked to imitate 2 tapping tasks: (1) tap twice with left index finger and then twice with right index finger, repeating the pattern 5 times at a rate of about 2 taps/sec; (2) tap once with left index finger and twice with right index finger, repeating the pattern 5 times	Either task performed correctly

was not entirely satisfactory. A simple pass-fail scoring system seemed to be more reproducible than the graded scoring system provided by Touwen and Prechtl. Furthermore, many items, including cranial nerve functions, assessment for tremor, and reflexes, were normal for most children in all groups. Other items, such as spooning of hands and choreiform movements, were difficult to score, with limited inter-observer correspondence. Not all the remaining items were appropriate for both age-groups, *e.g.* hopping on one foot was too difficult for most three-year-olds in both groups. Also, although sufficient items showed significant discrimination between normal and at-risk three-year-olds, there were ceiling effects on several of these items for five-year-olds, such as tandem gait forward and alternating (pronation-supination) hand movements.

Because of these ceiling effects in the five-year-old group, a second group of five-year-olds was tested. This additional group included 51 normal and 51 at-risk children. The tasks given included all the items that discriminated between normal and at-risk five-year-old children in the first group. In addition, three new, more challenging items were added (tandem gait backward and two tapping tasks). Table II lists all items included in the final tests for three- and five-year-

TABLE III
Percentages of normal and at-risk 3-year-old children failing each neurological task

Task	*Normal*		*At-risk*		*p*	*z*
	M (N = 27)	*F* (N = 23)	*M* (N = 34)	*F* (N = 16)		
Walk on toes	4	0	41	13	<0·01	4·00
Walk on heels	4	17	44	44	<0·01	2·80
Tandem gait	15	4	41	38	<0·01	3·45
Touch localization	3	0	29	25	<0·01	3·64
Restless movements	44	17	53	38	>0·25	0·816
Hand co-ordination	22	17	32	31	>0·25	1·36

TABLE IV
Percentages of normal and at-risk 5-year-old children failing each neurological task

Task	*Normal*		*At-risk*		*p*	*z*
	M (N = 38)	*F* (N = 13)	*M* (N = 38)	*F* (N = 13)		
Walk on toes	3	0	8	15	<0·05	1·70
Walk on heels	5	0	32	23	<0·01	3·51
Tandem gait backward	74	67	95	92	<0·01	2·88
Restless movements	10	8	26	31	<0·01	2·21
Downward drift	26	8	42	46	<0·01	2·28
Hand co-ordination	0	0	5	0	NS	0·72
Hopping (10 times)	10	25	79	62	<0·01	6·22
Hopping (twice)	3	0	8	15	<0·05	1·70
Alternate tapping	0	0	11	8	<0·01	2·32
Complex tapping	56	42	97	92	<0·01	4·71

olds, and the criteria for passing each item.

Follow-up study.
The second group of five-year-old children was recalled two years later at age seven. Class placement in regular or special education classes and IQ were ascertained. IQ was measured by the Wechsler Intelligence Scale for Children —Revised (WISC-R). The predictive value of the neurological (neurodevelopmental) examination at age five for class placement and IQ at age seven was determined.

Results

Sensorimotor (neurodevelopmental) test data
Tables III and IV show the percentages of children who failed each neurological test item for normal and at-risk three-year-olds, and normal and at-risk five-year-olds. Small but statistically significant differences between boys and girls were noted at age three: normal girls performed better, especially on the 'restless movements' task, but a female advantage was no longer evident at age five. However, the number of girls in the normal five-year-old sample may be too small for reliable detection of subtle differences.

The six items for age three and the 10 items for age five listed in Tables III and IV may be considered as representing sensorimotor screening tests for early detection of preschool children with neuro-developmental disorders. These tests are easily marked, with scores ranging from 0 (all items passed) to 6 (all items failed) for the three-year-olds and from 0 to 10 for the five-year-olds. Figures 1 and 2 show the percentages of normal and at-risk children achieving a given score at three and five years. For

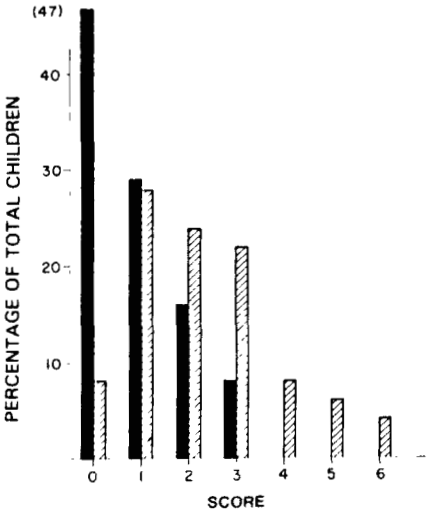

Fig. 1. Distribution of three-year-old normal and at-risk children by neurological test scores. Solid bars = control children, striped bars = at-risk children.

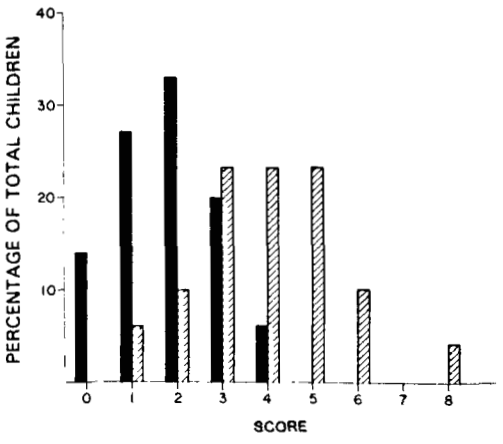

Fig. 2. Distribution of five-year-old normal and at-risk children by neurological test scores. Solid bars = control children, striped bars = at-risk children.

TABLE V

Correlation coefficients (Pearson Correlation Matrix) between neurological test score at age 5 and WISC-R subtests at age 7

	Correlation coefficient
Full-scale IQ	−0·545
Verbal IQ	−0·420
Information	−0·228
Similarities	−0·263
Arithmetic	−0·452
Vocabulary	−0·326
Comprehension	−0·283
Digit span	−0·390
Performance IQ	−0·480
Picture completion	−0·248
Picture arrangement	−0·414
Block design	−0·344
Object assembly	−0·206
Coding	−0·451
Mazes	−0·266

three-year-olds, scores of 3 and above were strongly related to placement in the at-risk group. 40 per cent of the at-risk group, but only 8 per cent of normal children, had scores ranging from 3 to 6. In contrast, 47 per cent of normal children, but only 8 per cent of at-risk children, had scores of 0. In the five-year-old group, scores of 4 and above correlated highly with placement in the at-risk group. 61 per cent of the at-risk children, but only 6 per cent of the normal group, had scores of 4 and above; whereas none of the normal group had a score above 4, and 41 per cent of normal children, but only 6 per cent of at-risk children, had scores of 0 or 1.

Follow-up study

Seventy-nine of the 102 children in the five-year-old group (77 per cent) were available for follow-up two years later. The remaining 23 subjects had moved away from the district. These 79 children were tested using the WISC-R. The correlation between neurological test score at age five and WISC-R at age seven was −0·55. This means that a poor test score at age five correlated with a lower full-scale IQ at age seven. The correlation for Verbal IQ (VIQ) was −0·42, slightly lower than that for Performance IQ (PIQ) (−0·48). Correlation coefficients for the various subtests are provided in Table V. A plot of IQ at age seven against neurological test score at age five years shows a linear relationship across the entire range of neurological test scores (Fig. 3).

Large discrepancies between VIQ and PIQ of 30 points or more were found in seven of the 79 children at follow-up. Less than one case per 100 with such a discrepancy would be expected in a

normal population (Kaufman 1979). Six of these seven children had neurological test scores of 4 or greater (21 per cent of the total number with such scores). In one case VIQ was greater than PIQ. This child appeared to fall into the category of 'clumsy children' with perceptual deficits (Gubbay *et al.* 1965, Gubbay 1975). PIQ exceeded VIQ in the other five children—a group with specific language disorders. One child with PIQ 30 points above VIQ, superior over-all intelligence (FIQ 128), normal neurological score (0), and normal class placement, appeared to be a normal variant.

Table VI shows the relationship between neurological test score at age five years and class placement at age seven. Only 14 per cent of children with neurological test scores of 4 and above were in their expected class placement (second grade). 41 per cent were in first grade and 45 per cent were in special education. In contrast, 74 per cent of children with scores below 4 were in second grade, 18 per cent in first grade, and only eight per cent in special education. The mean neurological score for those in second grade was 1·86 (SD 1·26), for those in first grade it was 3·81 (SD 1·70), and for those in special education 4·35 (SD 1·54) ($p<0·0001$).

Our follow-up of five-year-olds shows that both the school system's assessment and the neurological screening test accurately identified nearly all the children who needed special educational help two years later. Only two of 40 children identified as normal at age five were below class placement at age seven; both were in regular classes, one grade below age level. Both had been classified as normal by school assessment and by the neurological screening test.

The question whether some children were wrongly classified as handicapped by school assessment and/or by the neurological screening test is more difficult to answer. Some children thought to be at risk at age five functioned normally at age seven, but it cannot be said whether this was due to remedial education during the two intervening years or whether these children would have done well without remedial teaching. Nine of 39 children placed into remedial programs at age five on the basis of the school assessment had FIQ, VIQ and PIQ scores of 100 or above at age seven and were in normal first- or second-grade classes. Seven of these nine children had normal neurological scores (0 to 3) at age five. On the other hand, the neurological test would have classified as 'normal' six children who still needed remedial teaching at age seven, and who had been correctly identified by school screening.

TABLE VI

School placement at age 7 related to neurological test score at age 5*

	Neurological test scores						
	0	*1*	*2*	*3*	*4*	*5*	*6-8*
Second grade	6	11	12	8	3	1	0
First grade	0	2	3	4	3	8	1
Special education	0	0	2	2	7	2	4

*The numbers represent the number of children in each category.

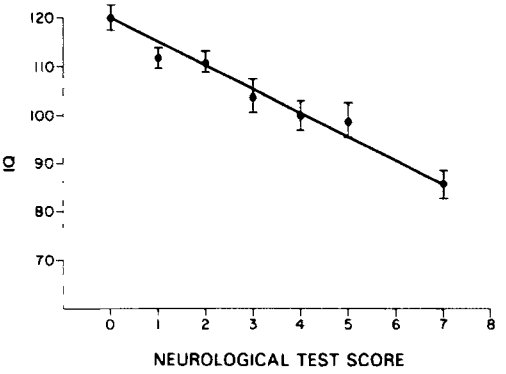

Fig. 3. Relationship between neurological test score at age five years and FIQ on the Wechsler Scale for Children at age seven. The error bars represent 1 SEM.

Discussion

In the present study, neurological tasks were given to children identified as at-risk for cognitive impairments and to age-matched controls. It was possible to identify tasks that discriminate normal and at-risk children, and to obtain normative data on these tasks.

Our findings suggest that a few simple neurological tests can be used to help identify preschool children who are at risk for learning disabilities. Very simple, easily scored tasks such as touch localization,

walking on toes, walking on heels and tandem-gait were useful between the ages of three and five years. These tests are readily administered as part of the routine pediatric examination of children at these ages. The tasks differ somewhat for three- and five-year olds. Small sex differences in neurological maturation were noted at age three, confirming in preschool children what has been noted already in older children (Adams *et al.* 1974, Gillberg *et al.* 1983, Younes *et al.* 1983). Our test items at five years old showed no significant sex differences, and the same norms are therefore applicable to both sexes at that age.

At present, we have no formal follow-up data for the three-year-old group, because they are not yet old enough for assessment of success in school. However, we believe that the predictive value of the three-year-old test is similar to that of the five-year-old test. The results for a group of children selected in a fashion similar to that of the five-year-olds gave very similar differentiation between normal and at-risk groups.

Initially, we had expected that the neurological screening test might specifically identify so-called clumsy children (Gubbay *et al.* 1965, Gubbay 1975), who would show deficits at age seven primarily in performance subtests on the WISC-R scale, and that it might miss children in whom language delays predominate. Our follow-up sample contained only one clear example of a clumsy child, who indeed had performed poorly on the neurological test at age five. More interestingly, high (abnormal) scores on the neurodevelopmental test at age five also characterized those children whose deficits at age seven were largely confined to language functions.

It therefore appears that neurological screening at age five reliably identifies children with large discrepancies between verbal and performance IQ in either direction. These children are usually considered to have specific learning disabilities. Additionally, the test distinguishes normal children from a much larger group of children, *i.e.* those with mild global delay in cognitive functions. As a group these children showed a persistent need for special educational help two years later; their WISC-R IQ scores were lower globally than those of children with normal neurological test scores, although they fell within the accepted normal range of 80 and above. It appears that many of these children had a widespread neurodevelopmental lag, involving cognitive abilities as well as motor function and sensory discrimination.

Only a few neurological tests helped to distinguish normal from at-risk children. Many items of the classic neurological examination of the child (Paine and Oppé 1966, Touwen and Prechtl 1970) failed to discriminate. Inclusion of these items actually decreased the differences between the groups, presumably through random variation introduced by occasional abnormal findings in both the normal and disabled groups. This does not mean that these items, including examination of cranial nerves and of reflexes, may not be of value in identifying some rare subgroups of learning-disabled children. However, for screening populations of children, the short examination is superior both in its ability to differentiate between normal and at-risk children and in its ease of administration.

The present study provides data that enable the pediatrician or pediatric neurologist to assist educators in the early identification of those children who may need remedial education. Children who fail the neurological screening test at age three or five might need to be considered for neuropsychological testing and, if this is confirmatory, for special educational programs. However, the neurological screening test alone, without the confirmation of further testing, is insufficient to predict success in school or to decide the need for early remediation.

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SUMMARY
A set of neurological tasks was administered to normal three- and five-year-old preschool children as well as to equal-age children identified as being at-risk for learning disabilities. 12 neurological test items were identified that differentiated normal from at-risk children at one or both ages. Follow-up of the five-year-olds at age seven showed a significant linear relation between scores on neurological tasks and the Wechsler Intelligence Test for Children. The neurological examination at age five also had predictive value regarding class placement at age seven. The findings suggest that a simple neurological test may be helpful for the early identification of preschool children who are at risk for learning difficulties.

RÉSUMÉ
Discrimination des enfants d'âge pré-scolaires, normaux ou à risque à partir de tests neurologiques
Un ensemble de tests neurologiques fut administré à des enfants normaux d'école maternelle, âgés de trois ou de cinq ans et à des enfants de mêmes âges identifiés comme étant à risque de difficultés d'apprentissage. Douze tests neurologiques furent isolés, qui différentiaient les enfants normaux et ceux à risque, à l'un ou aux deux âges. Le suivi des enfants de cinq ans à sept ans montrait une relation linéaire significative entre les tâches neurologiques et le test d'intelligence de Wechsler pour enfants. L'examen neurologique à cinq ans avait aussi une valeur prédictive sur l'orientation en classe à sept ans. Les données suggèrent qu'un simple test neurologique peut être utile pour l'identification précoce des enfants d'âge préscolaire à risque de difficultés d'apprentissage.

ZUSAMMENFASSUNG
Unterscheidung von normalen- und Risikovorschulkindern anhand von neurologischen Tests
Gesunde drei- und fünfjährige Vorschulkiner, sowie gleichaltrige Kinder mit Lernschwäche wurden mit einer Reihe von neurologischen Tests untersucht. Es wurden 12 Testaufgaben ausgewählt, die die normalen von den Risikokindern in einer oder beiden Altersgruppen differenzierten. Kontrolluntersuchungen der fünfjährigen im Alter von sieben jahren zeigten eine signifikante lineare Korrelation zwischen den neurologischen Scores und dem Wechsler Intelligenztest für Kinder. Die neurologische Untersuchung im Alter von fünf Jahren hatte auch prognostischen Wert hinsichtlich der Klassenzuordnung mit sieben Jahren. Die Befunde zeigen, daß ein einfacher neurologischer Test die frühzeitige Einordnung von Vorschulkindern mit dem Risiko einer Lernschwäche erleichtern kann.

RESUMEN
Discriminación de preescolares normales y con riesgo por medio de tests neurológicos
Un grupo de tareas neurológicas fueron administradas a niños preescolares de tres y cinco años, al igual que a niños de la misma edad identificados como teniendo riesgo de alteraciones del aprendizaje. Se identificaron 12 items neurológicos que diferenciaban los niños normales de los con riesgo en una o ambas edades. El seguimiento de los de cinco años a la edad de siete mostró una relación lineal significativa entre los puntajes de las tareas neurológicas y el test de Wechsler para niños. El examen neurológico a la edad de cinco años tenía también un valor predictivo con respecto a la clase a ir a la edad de siete años. Los hallazgos sugieren que un simple test neurológico puede ayudar a la identificación precoz de los niños preescolares que estan con riesgo de sufrir dificultades para el aprendizaje.

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