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Neurological Soft Signs and School Achievement: The Mediating Effects of Sustained Attention

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A group of 115 black male adolescents drawn from a clinically unselected birth cohort, half of whom were known to have had neurological soft signs at age 7, were examined at age 17 to determine the relation between soft signs and performance on standard tests of school achievement and sustained attention. Three signs measured at age 17—dysgraphesthesia, difficulties with rapid alternating movements (dysdiadochokinesis), and motor slowness—were related to lower concurrent and past IQ and to impaired performance on laboratory and paper-and-pencil measures of sustained attention. The relation between signs and the attentional measures remained significant after IQ was statistically controlled. The three age 17 soft signs as well as age 7 signs were related to impaired performance on standardized tests (age 17) of school achievement. Most of the relation between signs and school achievement could be accounted for by the variance signs shared with sustained attention. One sign, mirror movements, was unrelated to all other attentional and cognitive measures.

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Neurological "soft" signs have been described as nonnormative performance on a neurological examination of motor and sensory functioning in the absence of a focal lesion (Shafer, Shaffer, O'Connor, & Stokman, 1983). Examples of the soft signs include mirror movements (which involve involuntary movement in the hand opposite the hand engaged in a simple task), difficulties in fluidly executing rapid alternating movements such as the pronating and supinating of the hand (also known as dysdiadochokinesis), motor slowness, and dysgraphesthesia (difficulties in identifying figures drawn on the palm of the hand). The origin of such signs is unknown. Nichols and Chen (1981) found that only a small number of many possible perinatal complications discriminated children diagnosed for soft signs from normal controls. However, they found greater concordance for signs in mono- as compared with dizygotic twins. Moreover, other data on familial aggregation "offer some support for a genetic influence" (p. 261).

A number of investigators have observed that signs are associated with learning problems (Adams, Kocsis, & Estes, 1974; Stine, Saratsiotis, & Mosser, 1975; Wolff & Hurwitz, 1973; Hertzig, 1981) and lower IQ (Hertzig, 1982; Bortner, Hertzig, & Birch, 1972; Gilberg & Rasmussen, 1982; Shaffer et al., 1985). In studies involving referred samples, soft signs have been found to be associated with specific varieties of psychiatric disorder (Quitkin, Rifkin, & Klein, 1976; Paulsen, 1978) and delinquency (Wolff, Waber, Bauermeister, Cohen, & Ferber, 1982). However, given possible referral biases, more attention should be paid to studies of unselected populations. Using a sample that was unselected for the psychiatric disorders under investigation, Shaffer et al. (1985) found that soft signs diagnosed at age 7 were predictive of anxiety-withdrawal and affective disorders in late adolescence.

The purpose of this study was to examine, in an unselected sample of 17-year-olds, the relation of three types of motor signs (mirror movements, difficulties in fluidly executing rapid alternating movements, and motor slowness) and one sensory sign (dysgraphesthesia) to standardized measures of school achievement and difficulties in sustained attention as measured by objective laboratory techniques. The signs were measured reliably as continuous factors. We know of no other studies that have linked soft signs to both achievement test performance and sustained attention in an unselected sample.

This study is one of a series aimed at examining the predictive value of soft signs. The series included studies of psychiatric disorder (Shaffer et al., 1985; Schonfeld, Shaffer, O'Connor, & Portnoy, 1988), intelligence (Shaffer et al., 1985; Schonfeld et al., 1988), and persisting abnormality in neurological test performance (Shafer et al., 1986). We specifically explored the relation of soft signs to achievement and sustained attention. In contrast to selective attention, which involves dividing attention between competing sources of information, sustained attention implies concentrating on one source of information over time (Davies, Jones, & Taylor, 1984). We therefore hypothesized that the relation of soft signs to reading and math performance would be mediated by difficulties in sustaining attention.

The sample consisted of black males who participated in a longitudinal study of the psychiatric and medical sequalae, in adolescence, of neurological soft signs diagnosed at age 7 (Shaffer et al., 1985). Black males were followed for practical reasons: At the medical center at which the study was conducted, they had the highest prevalence rate of soft signs at age 7. This selection decision, however, limits the generalizability of the findings to other racial and ethnic groups, as well as to females. Nevertheless, the methodological strengths of the study make it possible to examine achievement and attentional difficulties related to signs. First, the subjects were representative of youngsters from black northern Manhattan homes. Second, by having approximately equal numbers of subjects who were diagnosed positive and negative for soft signs at age 7, and given findings demonstrating the 10-year consistency of the signs (Shafer et al., 1986), variance in the age 17 measures of signs was maximized. Third, data assessing the environmental disadvantages of the subjects were collected. Fourth, IQ and achievement were measured with the appropriate Wechsler and Peabody scales. Finally, sustained attention was assessed with sophisticated laboratory measures as well as with paper-and-pencil tests.

METHOD

Subjects

Subjects were members of the Columbia-Presbyterian Medical Center chapter of the nationwide Collaborative Perinatal Project (CPP). Between 1957 and 1963, a one-in-five consecutive sample of mothers presenting for prenatal care were accepted into the study. Only planned adoption donors and mothers who failed to present for prenatal care were excluded. A CPP research team followed the children until their 8th year. Two groups of call-back subjects were followed by a different team at age 17. One group consisted of nonretarded black English-speaking males who met the following criteria: membership in the 1962–1963 birth cohort, a positive diagnosis for any one of a number of neurological soft signs during the age 7 medical examination, and no evidence of other neurological problems. Six types of neurological soft signs were diagnosed in this group: awkwardness or poor coordination in finger–nose touching, finger pursuit, and fine motor activity (the most frequently diagnosed sign); dysdiadochokinesis (difficulties in performing rapid alternating movements of the hands or feet); mirror movements; tremor; dysgraphesthesia (incorrect identification of a predisplayed symbol traced on the palm when blindfolded); and astereognosis (incorrect identification of three-dimensional objects on the outstretched hand when blindfolded). The second group of subjects consisted of nonretarded males matched to members of the first group on date of birth, race, and language; members of the second group, however, were required to exhibit no evidence of soft or hard neurological signs.

A total of 63 males were considered to have met criteria for membership in the first group. They were matched with 63 males who had been free of signs at age 7. A total of 61 sign-positive males were located and assessed at age 17. Three of the 61 were later excluded because either a major neurological disorder or a tic, missed in an earlier review of the medical records, was documented in a later record check, thus reducing the first group to 58. Of the 63 in the second group, 57 were reexamined at age 17.

Most of the subjects were examined at New York State Psychiatric Institute in New York City; however, some of the subjects' domiciles were located outside of the New York metropolitan area (e.g., rural Maryland, an upstate prison). Some subjects would or could not come to New York City for examination ($n = 12$); therefore, examiners were sent to see them. Owing to the study team's reluctance to transport the apparatus, the chief difference between the New York City and out-of-town examinations was the omission of the part of the attentional examination that involved electronic equipment. Another 3 subjects seen in New York City did not receive any part of the attentional examination.

Procedure

At the age 17 follow-up, the adolescents were administered psychiatric, neurological, attentional, and cognitive examinations on the same day by independent examiners with no knowledge of the subject's status on the age 7 measures. The adolescent's parent, usually his mother, was also independently interviewed. A description of the psychiatric assessment procedures can be found in Shaffer et al. (1985). The parent interview elicited demographic and educational information. Seven interview items were used to construct an environmental disadvantage scale: single parenthood, four or more siblings, incomplete education in the mother or father, welfare dependency, low income, and dissatisfaction with housing. These factors are commonly held to be associated with lower school achievement and could reasonably be assumed to be external to the adolescent's neurological status. The items were standardized such that a value of 0 was given for the optimal response category (e.g., college degree in the paternal education item) and a value of 1 was given to the most adverse response category (e.g., elementary school education). Intermediate response alternatives were assigned proportionally to intermediate values. The items were then aggregated to yield a scale having an Alpha coefficient of .62.

Neurological Examination

The neurological examination conducted when the subjects were age 17 included measures of soft signs, some of which were reliably measured: mirror movements, difficulties performing rapid alternating movements (dysdiadochokinesis), dysgraphesthesia, and motor speed (Shafer et al., 1986). Mirror movements were assessed in the hand not assigned to perform a finger apposition task (marching each finger past the thumb). Mirror movements were not assessed in the test for motor speed described below. Difficulties in rapid alternating movements were assessed by counting failures to alternate and identifying dysrhythmias in pronating and supinating the hand. Motor speed was assessed by timing the subjects executing a set number of pronating and supinating movements of each hand, heel-toe tapping, and finger apposition movements. Dysgraphesthesia refers to errors made when the blindfolded subject was asked to identify figures, a square, the letter *X*, the numeral 3, and a 0, drawn with a blunt stylus on the palm of his hand. A more complete description of the neurological examination may be found in Stokman et al. (1986).

Unlike the signs diagnosed at age 7, the age 17 signs were measured as continuous variables. Counts and timings were range-standardized before being aggregated. A score of 0 was given to the optimal performance and a score of 1 to the poorest performance, with intermediate performances assigned proportionally intermediate values. In order to construct present/absent dichotomies to tabulate the number of abnormal signs and to parallel clinical procedures, each sign dimension was reconstituted such that approximately 15% of the subjects whose performance on that dimension was farthest from optimal were considered to be positive for that sign. The remaining 85% of the subjects were considered negative for the sign. In the case of two signs, mirror movements and rapid alternating movements, the break points at which we divided the sample into sign-positive and -negative groups were adjusted slightly on the basis of clinical judgments elicited from a panel of neurologists (Shafer et al. 1986).

About half the subjects were diagnosed for signs at age 7, the other half having been found to be sign-free. All statistical analyses pertaining to the age 17 signs were conducted regardless of the subjects' neurological status at age 7. The analyses relied more heavily on the age 17 measures because their psychometric properties were found to be adequate (Stokman et al., 1986). By contrast, the earlier study team did not investigate the psychometric properties of the age 7 measures. The later team, however, obtained indirect evidence for the reliability of the age 7 measures (Shaffer et al., 1985).

Attentional Examination

The measures of sustained attention included (1) the dynamic A-X version (Buchsbaum, Murphy, Coursey, Lake, & Ziegler, 1978) of the continuous performance test (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956); (2) a modified version of the Sutton-Zubin (S-Z) reaction time paradigm (Sutton, Hakerem, Zubin, & Portnoy, 1961; Sutton & Zubin, 1965); (3) cancellation tests (Davies & Davies, 1975; Diller & Weinberg, 1970; Weinberg et al., 1977; Mohan, Sehgal, & Bhandari, 1982); (4) the Trail Making Test (Armitage, 1946; Reitan, 1955).

CPT. The hardware requirements of the CPT included the Yankee I portable microcomputer manufactured by Sunrise Systems Inc. Linked to the microcomputer was the subject box, which held an aircraft single-plane readout to display 1-inch characters and a green display light. The stimulus characters displayed were the letters *A, B, C, E, F, L, M, N, P,* and *X*. The subject sat facing the subject box and was instructed to press the button before him each time he saw the letter *X* appear after the letter *A*. The examiner encouraged the subject to use his preferred hand. The subject was then told that if he pressed the button quickly enough a green light on the front panel of the subject box would go on. Next, the subject was informed that if he consistently succeeded in getting the green light to go on the machine would speed up slightly, and that if he did not succeed the machine would slow down. The examiner then instructed the subject to try to make the machine go "at top speed, as fast as it can." The subject was given a practice trial before the main test began.

The number of late correct responses and the number of omission errors were added over every span of five critical stimuli. If the sum was two no adjustment was made for the next series of five stimuli. If the sum was less than two the interstimulus interval (ISI) for the next series of five stimuli was decreased by one-sixteenth. If the sum was greater than two the ISI was increased by one-sixteenth.

For each of five blocks of trials the initial ISI and stimulus duration were 80 and 20 msec, respectively. Thus, each block could be considered a separate "test" item. A total 80 stimuli were presented in block 1, 100 in block 2, 120 in block 3, 140 in block 4, 160 in block 5. Final ISIs were recorded for each block; however, for block 5, number of correct responses, commission errors, omission errors, and late correct responses were also recorded. In each block the ratio of critical to noncritical stimuli was approximately 1:5. To reduce the amount of usable data to manageable levels, the final ISIs from the five blocks of the CPT trials were averaged to construct a final ISI scale. Since the final ISIs from each block were highly correlated with each other (r(mdn) = .79, range = .67 − .90), the alpha coefficient for the scale was high (Alpha = .95).

Modified Sutton-Zubin Reaction Time Paradigm. As with the CPT, the modified S-Z reaction time paradigm (Sutton et al., 1961; Sutton & Zubin, 1965) employed the Yankee I portable microcomputer linked to the subject box. The reaction time response button was attached to the subject box.

Before a trial began the subject heard a 1.9-Hz warning tone, at which point he placed the index finger of his preferred hand on the response button. The warning tone was followed by a preparatory interval of randomly varying duration. The preparatory interval could assume the following durations: 0.5, 1.0, 2.0, 5.0, and 10.0 sec. The presentation of an imperative stimulus ended the preparatory interval. The imperative stimulus was either a 2.9-Hz tone or a light. The subject's response to the imperative stimulus was to lift his finger from the response button as quickly as possible, concluding the trial. There were six independent blocks of trials. A block consisted of 30 consecutive trials, 15 of which began with the auditory imperative stimulus and 15 with the visual stimulus. The imperative stimuli were randomly ordered. For each block, mean reaction times in response to the auditory and visual imperative stimuli were computed. The mean reaction times for the six visual and six auditory S-Z blocks were averaged to create auditory (Alpha = .94) and visual (Alpha = .88) S-Z reaction time scales.

Cancellation Tests. Each subject was given six sheets. A target stimulus was centered and circled on the top of each sheet. The target stimulus was a triad of letters (tests 1 and 6), numbers (tests 2 and 5), or geometric figures (tests 3 and 4). On each page, just below the target stimulus, there were 15 rows and 10 columns of comparable triads. The subject was instructed to examine each page and cross out every triad that identically matched the target stimulus on top. Time to complete a sheet and number of omission and commission errors were recorded. On tests 5 and 6 subjects made virtually no commission errors, probably a result of practice effects and lack of test difficulty; commission errors made in tests 5 and 6 were therefore not included in the scale construction. The six elapsed times (ETs), the six sets of omission errors (OEs), and the four sets of commission errors (CEs) were summed for the purpose of scale construction. The alpha coefficients for the ET, OE, and CE scales were .89, .73, and .26, respectively. Since the reliability of the third scale was unsatisfactory, it was excluded from the analysis.

Trail Making Test. In Part A of the TM test the subject, after a practice example, was presented a sheet of paper with 25 circles each enclosing a number from 1 to 25. The circles were randomly ordered. The subject was instructed to draw a line from circle 1 to circle 2, then from circle 2 to circle 3, and so on to circle 25, working as fast as he could. Part B of the Trail Making Test (Armitage, 1946; Reitan, 1955) requires the subject to pay continuous attention to connections between alphabetic and numerical stimuli in overcoming two overlearned response tendencies. In Part B, the subject, after a practice session, was presented a sheet of paper with 25 circles, each enclosing one of 13 numbers (1 to 13) or 12 letters (A through L). The circles were randomly ordered. The subject was instructed to draw a line from circle 1 to circle A, then from circle A to circle 2, then from circle 2 to circle B, and so on to circle 13, working as fast as he could. In both Parts A and B the examiner had the subject correct misorderings during testing. Elapsed time and numbers of misordered circles were recorded for Parts A and B. A stopwatch was used to record elapsed time in both the cancellation and TM tests. For a more detailed description of the test see Armitage (1946) and Reitan (1955). The ETs for Parts A and B of the TM Test were converted to z scores because they were correlated but had very different means and variances. The standardized ETs were then summed to yield an ET scale with an alpha coefficient of .68. In contrast to Part B, there was almost no variance in the number of misordered circles in Part A (subjects rarely erred in ordering the circles); therefore, the counts of misordered circles were not pooled and only the number of misordered circles in Part B was included in the analyses.

Cognitive Examination

The cognitive battery consisted of the Wechsler Adult Intelligence Scale (WAIS), the Peabody Individual Achievement Tests (PIAT) for reading comprehension, mathematics, and spelling, and the Wide Range Achievement Test (WRAT) for word reading (recognition).

Archival Data

An earlier generation of CPP investigators collected data on all subjects between birth and age 7. The archival data we retrieved included age 4 Stanford-Binet and age 7 WISC (prorated from seven subtests) IQ scores as well as the neurological soft signs detected at age 7. Unlike the continuous age 17 measures, each age 7 measure was coded present/absent.

RESULTS

Relations Among the Attentional Measures

As expected, the final ISI of block five was highly correlated to the sum of omission errors and late correct responses ($r = .85$, $p < .001$), indicating that the apparatus operated satisfactorily. Number of commission errors, which by virtue of the operation of the CPT was independent of the ISI, was significantly related ($r = .18$, $p < .05$, one-tailed) to the final ISI scale; slower performance was mildly related to more commission errors.

Table I presents the correlations between each pair of the age 17 attentional scales. The correlation matrix indicates that measures tended to be significantly intercorrelated. Measures involving elapsed time tended to be more highly correlated to one another than to error counts (cancellation test omission errors and Trail Making misordered circles). Table I also shows that, on the average, subjects with slower speeds on the ISI and S-Z scales tended to make more omission errors and misorder more circles.

Attention and IQ

Since WAIS IQ is an omnibus measures of cognitive functioning having subtests thought to tap attentional processes, it was expected that IQ would share variance with the attentional measures. Table II presents zero-order correlations between each of the attentional measures (a high score on

Table I. Correlations Among the Attentional Measures[a,b]

	ISI	S-Z Aud	S-Z Vis	Canc ET	Canc OE	TM ET
S-Z Aud Scale	.46[f]					
S-Z Vis Scale	.58[f]	.72[f]				
Canc ET Scale	.48[f]	.28[e]	.28[e]			
Canc OE Scale	.36[f]	.14[c]	.29[e]	−.14[c]		
TM ET Scale	.56[f]	.46[f]	.53[e]	.51[f]	.27[e]	
TM Misord B.	.39[f]	.29[e]	.38[f]	.21[d]	.31[f]	–

[a]All tests are one-tailed.
[b]The correlation between the Trail-Making Elapsed Time Scale and the number of misordered circles is not presented because in test B time on task depends in part on the number of misorderings.
[c]$p < .10$.
[d]$p < .05$.
[e]$p < .01$.
[f]$p < .001$.

Table II. Correlations of Attentional and IQ Measures[a]

Age 17 Attentional measures	IQ Measures Age 4 SB	Age 7 WISC FIQ	Age 17 WAIS FIQ
CPT Final ISI Scale	−.36[d]	−.52[d]	−.59[d]
S-Z Aud Scale	−.09	−.21[b]	−.42[d]
S-Z Vis Scale	−.19[b]	−.39[d]	−.53[d]
Canc ET Scale	−.21[b]	−.38[d]	−.39[d]
Canc OE Scale	−.27[c]	−.18[b]	−.26[c]
TM ET Scale	−.44[d]	−.58[d]	−.64[d]
TM Misord B.	−.33[d]	−.32[d]	−.43[d]

[a]All tests are one-tailed.
[b]$p < .05$.
[c]$p < .01$.
[d]$p < .001$.

any of these measures reflects poor performance) and concurrent and past measures of IQ. All age 17 measures of attentional difficulties were significantly and inversely correlated with age 4, 7, and 17 IQ. As expected, the correlations of the attentional measures with the age 4 and 7 IQ measures were slightly weaker than the correlations with concurrent IQ. To control for the overlap in the IQ and attentional measures, a new IQ variable was constructed such that variance shared with a contemporary attentional measure was removed. The constructed IQ variable consisted of the age 17 full-scale WAIS IQ residualized for variance it shared with the final ISI scale.

Soft Signs and IQ

Table III reveals moderate, negative correlations between the age 17 measures of dysgraphesthesia, difficulties performing rapid alternating movements, and motor slowness and the IQ measures obtained for ages 4, 7, and 17. As expected, the correlations between age 17 signs and age 4 and age 7 IQ were slightly weaker than the corrrelations between signs and concurrent IQ. Mirror movements is not presented in Table III because it was unrelated to each of the IQ measures. The number of dichotomously coded age 17 signs was significantly related to the cognitive measures. Table III also shows that the number of signs detected at age 7 was significantly related to concurrent, past (age 4), and future (age 17) IQ.

Dysgraphesthesia was the only sign significantly related to the constructed residualized IQ variable. The correlations between difficulties executing rapid alternating movements, motor slowness, and number of age 7 signs with age 17 IQ became nonsignificant or marginally significant when

Table III. Correlations of Soft Signs and IQ Measures[a,b]

	IQ Measures			
	Age 4	Age 7	Age 17	
Soft signs measures	SB	WISC FIQ	WAIS FIQ	Residual IQ
Dysgraphesthesia, age 17	$-.16^d$	$-.28^f$	$-.37^f$	$-.26^e$
Rapid alternating movements, age 17	$-.25^e$	$-.24^e$	$-.33^f$	$-.05$
Motor slowness, age 17	$-.32^f$	$-.34^f$	$-.38^f$	$-.11$
No. dichotomized signs	$-.33^f$	$-.37^f$	$-.38^f$	$-.14^c$
No. signs, age 7	$-.16^d$	$-.37^f$	$-.33^f$	$-.14^c$

[a] All tests are one-tailed.
[b] In the residual measure of age 17 WAIS IQ, variance associated with the final ISI scale was statistically removed.
[c] $p < .10$.
[d] $p < .05$.
[e] $p < .01$.
[f] $p < .001$.

the sustained attention, as operationalized by the final ISI scale, was controlled.

Because clinical lore on minimal brain dysfunction (MBD) has linked inattention, neurological signs, and verbal-performance (V-P) IQ discrepancies (see Nichols & Chen, 1981), we examined the relation between signs and V-P differences in the present data. Only one of the four age 17 signs, dysgraphesthesia, was significantly related to Verbal-minus-Performance IQ ($r = .18$, $p < .05$). Dysgraphesthesia, difficulties executing rapid alternating movements, and motor slowness were related to *both* lower verbal (r(mdn) = $-.37$) and performance (r(mdn) = $-.30$) IQ; however, mirror movements was unrelated to either verbal or performance IQ. The occurrence of discrepancies as "abnormal" as 15 points (Berk, 1982) was unrelated to the presence of any of the dichotomized age 17 signs variables.

Soft Signs and Attention

Table IV presents zero-order correlations between the attentional and neurologic performance measures. Dysgraphesthesia, difficulties performing rapid alternating movements, motor slowness, and the number of dichotomously coded age 17 signs were moderately correlated to the measures of sustained attention; however, when IQ was controlled the correlations were reduced in size, although most remained statistically significant. The number of age 7 signs was also correlated to the measures of sustained attention, correlations that were also reduced when IQ was controlled. Mirror movements, not shown in Table IV, was unrelated to the attentional measures.

Table IV. Correlations Between Attentional and Soft Signs Measures (with IQ Partialed)[a,b]

Attentional measures	Soft signs measures: Dysgraphesthesia		Rapid alternating movements		Motor slowness		Dichotomized signs		*N* of age 7 signs	
	Pearson	Partial	Pearson	Partial	Pearson	Partial	Pearson	Partial	Pearson	Partial
CPT ISI Scale	.29^{f}	.10	.50^{g}	.40^{g}	.47^{g}	.33^{g}	.45^{g}	.31^{g}	.36^{g}	.21^{e}
S-Z Aud Scale	.38^{g}	.27^{f}	.44^{g}	.35^{g}	.31^{g}	.18^{e}	.28^{f}	.29^{f}	.28^{f}	.22^{e}
S-Z Vis Scale	.34^{g}	.19^{e}	.47^{g}	.38^{g}	.25^{f}	.06	.40^{g}	.28^{f}	.38^{g}	.28^{f}
Canc ET Scale	.07	−.08	.17^{e}	.05	.36^{g}	.25^{f}	.27^{f}	.12	.24^{f}	.11
Canc OE Scale	.19^{e}	.11	.37^{g}	.31^{g}	.15^{d}	.05	.28^{f}	.19^{e}	.28^{f}	.23^{f}
TM ET Scale	.32^{g}	.12	.34^{g}	.18^{e}	.40^{g}	.23^{f}	.41^{g}	.19^{e}	.28^{g}	.09
TM Misord. B.	.33^{g}	.21^{e}	.26^{f}	.14^{d}	.33^{g}	.20^{e}	.40^{g}	.23^{f}	.31^{g}	.22^{f}
Freedom[c]	−.34^{g}	−.20^{e}	−.28^{f}	−.06	−.30^{g}	−.12	−.25^{f}	−.06	−.30^{g}	−.09
Percept.[c]	−.23^{g}	−.05	−.31^{f}	−.18	−.27^{f}	−.04	−.13^{d}	.03	−.29^{g}	−.17^{e}

[a]Full-scale WAIS IQ was partialed from the correlation coefficients except where otherwise indicated.
[b]All tests are one-tailed.
[c]The sum of the WAIS subtests not included in the factor scores was partialed.
$^{d}p < .10$.
$^{e}p < .05$.
$^{f}p < .01$.
$^{g}p < .001$.

To determine if a specific attention-related facet of the WAIS explained the signs–WAIS correlations, the signs variables were correlated with two factors consisting of contrasting sums of WAIS subtest scores: freedom from distractibility (digit span + arithmetic + digit symbol) and perceptual organization (block design + object assembly + picture completion + picture arrangement) (see Kaufman, 1982). For each factor, a partial correlation coefficient that controlled for the sum of the remaining subtests not included in the factor was also computed. Table IV indicates that both factors were similarly related to the various measures of signs. Signs, however, tended to be more strongly related to the laboratory and paper-and-pencil measures of sustained attention than to the subtest factors.

In order to depict how soft signs are related to differential performance on the attentional and cognitive measures, the subjects were grouped on the basis of the dichotomous measures of age 17 signs. The mean scores of subjects with no, one, and two or more dichotomous age 17 signs were compared by way of one-way analyses of variance. The results of these analyses (see Table V) indicate that with an increased number of signs, performance on each of the measures tends to decline.

Soft Signs and Achievement

Table VI indicates that dysgraphesthesia, difficulties performing rapid alternating movements, motor slowness, and the number of age 17 signs dichotomously coded were moderately related to poorer performance on the

Table V. Mean Performance on the Cognitive Variables by Age 17 Status on Three Dichotomized Soft Signs Variables[a]

	Scale units	No signs	One sign	Two signs	F	df	p
Final ISI	msec	222.1	255.4	269.3	12.15	2, 97	.001
S-Z Aud	msec	281.3	322.0	360.1	9.44	2, 96	.001
S-Z Vis	msec	381.0	530.4	686.9	9.82	2, 96	.001
Canc ET	min	67.6	77.4	79.1	4.62	2, 108	.02
Canc OE	errors	7.1	8.7	14.8	4.84	2, 108	.01
TM ET	z score	−0.23	0.36	0.84	10.11	2, 108	.001
TM Misord. B.	errors	0.77	1.38	2.25	4.82	2, 107	.01
WAIS FIQ	IQ	94.4	85.7	84.1	9.75	2, 108	.001
WAIS PIQ	IQ	94.2	87.6	86.4	4.30	2, 108	.02
WAIS VIQ	IQ	95.0	85.9	84.0	11.06	2, 108	.001
PIAT Rdg	IQ	92.2	81.4	77.0	12.71	2, 108	.001
PIAT Math	IQ	93.6	84.4	80.1	8.97	2, 108	.001
PIAT Spell	IQ	90.4	81.0	80.2	6.07	2, 108	.01
WRAT Wd Rec	IQ	98.5	83.7	82.9	10.56	2, 96	.001

[a]The dichotomized soft signs variables included dysgraphesthesia, difficulties with rapid alternating movements, and motor slowness. Mirror movements was not counted.

achievement tests. By contrast, mirror movements was either uncorrelated to achievement or correlated in a positive direction. The number of age 7 signs was also related to the achievement measures. Partial correlational analyses test the hypothesis that the relation of soft signs to poorer achievement results from the diminished capacity of adolescents with signs to sustain attention. We selected one of the laboratory measures of sustained attention, the final ISI scale, as a control variable in the subsequent analyses. Consistent with this view, Table VI indicates that the zero-order correlations between signs—especially for difficulties performing rapid alternating movements—and achievement measures were substantially diminished when final ISI was controlled.

Although the above analyses appear to explain the relation between soft signs and achievement in terms of an impaired capacity to sustain attention, the relation might be explained equally by the tendency of adolescents with signs to perform worse on IQ tests or to come from disadvantaged homes. The median correlation between full-scale IQ and the achievement measures was .65. The environmental disadvantage scale was also related to achievement test performance (r(mdn) = $-.27$). Environmental disadvantage was correlated to dysgraphesthesia, $r = .16$, $p < .05$, difficulties executing rapid alternating movements, $r = -.07$, n.s., and motor slowness, $r = .16$, $p = .05$. A more conservative test of the hypothesis that sustained attention mediates poorer achievement in adolescents with signs was therefore undertaken. The constructed residualized IQ variable and the environmental disadvantage scale were partialed from the zero-order signs-achievement correlations presented in Table VI. Residualized WAIS IQ, rather than uncorrected IQ, was employed in order to avoid overcontrolling for attentional variance. These second-order partial correlations are presented in Table VII. It is evident from the table that almost all signs-achievement correlations still met conventional levels of significance when disadvantage and residualized WAIS IQ were controlled. The final ISI scale was partialed after the second-order effects of residualized IQ and disadvantage were removed. As shown in Table VII, none of the correlations remained significant after the effects of the final ISI scale were removed in the third-order partialing. The partial correlational analysis was repeated substituting the mean of the two S-Z scales for the final ISI scale. The third-order partialing of the mean of the S-Z scales reduced the number of significant correlations to four. Thus, the relation between soft signs and achievement could be explained on the basis of signs-linked impairments in attentional functioning.

Finally, the third-order partials were recomputed substituting either the WAIS freedom from distractibility or the perceptual organizational factor (Kaufman, 1982) for the laboratory attentional measures. With either the freedom or perceptual organization factor included, at least 11 third-order partial correlations still met conventional levels of significance.

Table VI. Zero- and First-Order (Controlling for Attention) Correlations Between Continuous Measures of Soft Signs and School Achievement[a,b]

Attentional measures	Achievement measures: PIAT Reading comprehension, Pearson	PIAT Reading comprehension, Partial	PIAT Spelling, Pearson	PIAT Spelling, Partial	PIAT Math, Pearson	PIAT Math, Partial	WRAT Word recognition, Pearson	WRAT Word recognition, Partial
Dysgraphesthesia	−.34[f]	−.20[d]	−.24[e]	−.11[c]	−.36[f]	−.22[d]	−.32[f]	−.14[c]
RAM	−.32[f]	−.08	−.23[e]	−.06	−.27[e]	−.02	−.27[e]	.03
Motor slowness	−.43[f]	−.16[c]	−.29[f]	−.04	−.36[f]	−.13	−.40[f]	−.16[c]
Dichotomized signs	−.43[f]	−.20[d]	−.31[f]	−.07	−.38[f]	−.15[c]	−.40[f]	−.16[c]
Age 7 signs	−.28[f]	−.05	−.26[e]	−.09	−.30[f]	−.20[d]	−.25[e]	−.02

[a]All tests are one-tailed.
[b]The final ISI scale was partialed.
[c]$p < .10$.
[d]$p < .05$.
[e]$p < .01$.
[f]$p < .001$.

Table VII. Correlations Between Continuous Measures of Soft Signs and School Achievement Controlling for (1) Residualized Full-Scale IQ and Environmental Disadvantage, and (2) Residualized Full-Scale IQ, Environmental Disadvantage, and Attention[a,b]

	Achievement measures							
	PIAT Reading comprehension		PIAT Spelling		PIAT Math		WRAT Word recognition	
Soft signs measures	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Dysgraphesthesia	−.23[d]	−.02	−.15[c]	−.00	−.27[e]	−.08	−.20[d]	−.01
RAM	−.37[f]	−.14[c]	−.23[d]	−.04	−.26[e]	−.03	−.25[d]	−.01
Motor slowness	−.39[f]	−.13	−.20[d]	−.01	−.36[f]	−.08	−.34[f]	−.11
Dichotomized signs	−.41[f]	−.16[c]	−.21[d]	−.02	−.33[f]	−.06	−.33[f]	−.11
Age 7 signs	−.21[d]	−.01	−.19[d]	−.05	−.30[e]	−.11	−.11	−.10

[a]All tests are one-tailed.
[b]Residualized WAIS IQ and environmental disadvantage were partialed in the first step. The final ISI scale was partialed in the second step.
[c]$p < .10$.
[d]$p < .05$.
[e]$p < .01$.
[f]$p < .001$.

Tables VI and VII also indicate that the number of age 7 signs was also related to age 17 achievement. As in the case of the prior analyses, the relation of early signs to later achievement was weakened when attention was controlled. A set of analyses paralleling the partial correlational analyses was conducted using multiple linear regression procedures. Each achievement measure was regressed upon one of the three age 17 soft signs measures in step one. In the next step, residualized IQ and environment disadvantage were entered into the regression equation. In the last step, the final ISI scale was entered. Consistent with the partial correlational analyses, the regression weights for the soft signs measures tended to become nonsignificant when final ISI was controlled (from $p < .05$ or $p < .10$ to $p > .10$).

Bias Due to Attrition

There were three sources of missing subjects: (1) individuals examined out of town who were not administered the CPT and S-Z tasks ($n = 12$); (2) subjects examined in New York City who, because of scheduling or refusal, did not receive any attentional tasks ($n = 3$); (3) individuals not seen at age 17 ($n = 8$). Analyses were undertaken in which either the three groups or the second and third groups were merged and compared with the subjects who received the entire attentional examination. The analyses revealed no significant differences between groups on the age 4 Stanford-Binet IQ, the age 7 WISC IQ, and age 7 Digit Span and Coding.

DISCUSSION

A number of findings concerning the soft signs, attentional, and cognitive measures emerged. First, the attentional measures, particularly the measures that involved timings, were sufficiently correlated with each other to suggest they were measuring the same construct. Second, consistent with the view that IQ test performance partly reflects the capacity to sustain attention, the measures of sustained attention were significantly related to concurrent (WAIS) and past (WISC and S-B) IQ.

Third, in line with the view that signs reflect CNS disturbance, dysgraphesthesia, difficulties with rapid alternating movements, and motor slowness were related to low concurrent and past IQ. In addition, the number of signs detected at age 7 was related to past (age 4), concurrent, and future (age 17) IQ. Also consistent with this view are findings that indicated the three age 17 signs and the number of age 7 signs were significantly related to impaired performance on the laboratory and paper-and-pencil measures of sustained attention. The correlations between signs and the attentional measures tended to remain significant when IQ was controlled. The association between signs and attentional and cognitive difficulties also obtained when the age 17 signs were coded dichotomously.

Fourth, the findings pertaining to both verbal and performance IQ are inconsistent with the view that signs are part of a syndrome that includes verbal-performance discrepancies on the Wechsler scales. The pattern of results does not revive the old concept of MBD (Nichols & Chen, 1981) because of the nonspecificity of the IQ test findings. Fifth, signs were unrelated to special disability in learning one content domain (reading vs. math) in contrast to another: Signs were related to poorer performance on all achievement measures. Shaywitz, Shaywitz, McGraw, and Groll (1984) drew a similar conclusion using a predominantly white 10- to 12-year-old male sample. Much of the relation between signs and achievement could be accounted for by the variance signs shared with sustained attention. Finally, an analysis of attrition data indicated that subject loss probably did not unduly affect overall sample differences for IQ and attentional functioning.

One explanation of the pattern of correlations between the measures of signs and attention is artifactual, the result of shared methods of which speed is a common feature. The signs–attention correlations were stronger with attentional measures in which timing was an important feature (the S-Z, TM ET, and final ISI scales) than with measures based on error counts (TM misordered circles, cancellation test OEs). Motor slowness and difficulties executing rapid alternating movements were the signs most related to the attentional measures.

A number of conditions are inconsistent with the shared-methods explanation. Difficulties performing rapid alternating movements reflect errors made during the pronation-supination of the hand. The task is a measure of execution errors and dysrythmia in motor performance, not speed (despite the label). Motor slowness, by contrast, reflects lack of speed in executing that task. Dysgraphesthesia, a sign reflecting sensory kinesthetic impairment but not speed, was also related to inattention. Thus, only one soft-sign measure related to impaired attention was chiefly a measure of speed. The measures of sustained attention with the strongest correlation to soft signs also involved speed (final ISI and S-Z auditory and visual scales); however, whatever gross motor involvement was required for the labaratory attentional tasks was minimal. The only activity the subject had to perform in the context of the CPT and S-Z tasks was to press, or remove a finger from, a button.

In contrast to the shared-methods explanation, an alternative hypothesis is that each of the three soft signs reflects an impairment in CNS functioning bearing on (1) processing (not motor) speed and (2) nonspecific, global aspects of cognition. The processing-speed hypothesis is consistent with findings indicating that the three age 17 signs were related to impaired performance on the final ISI scale, both S-Z scales, and elapsed time measures for the cancellation and TM tasks controlling for IQ. The facet of speed that is tapped by the automated attentional measures appears to reside in the processing of sensory information needed in sustaining attention over a period of time. Experimental evidence (Botwinick & Thompson, 1966; Weiss, 1965) supports the view that differences in reaction time reflect central processes to a greater extent than peripheral or motor processes. Additional support for the processing-speed hypothesis comes from analyses indicating that the quicker subjects tended to make fewer errors.

The hypothesis that signs reflect CNS abnormalities bearing to global deficits in cognitive functioning is consistent with findings indicating that signs were inversely related to the concurrent, past, and, in the case of age 7 signs, future IQ. Support for the hypothesis is tempered by the finding that only dysgraphesthesia was significantly related to WAIS IQ when attentional variance, as reflected in the final ISI scale, was controlled. Motor slowness and difficulties performing rapid alternating movements were not related to IQ when sustained attention was controlled. The correlational data are compatible with the views that attentional resources constitute (1) a broad factor that is a precursor to intelligence or (2) processes within the framework of fluid ability (Stankov, 1983; also see Cattell, 1963; Schonfeld, 1986).

Three findings are at least suggestive of the view that attentional resources are prior to intelligence. First, the freedom from distractibility factor, a WAIS variable that presumably taps attentional processes, and the perceptual organizational factor were about equally related to the measures of signs. Attentional processes are likely to be embedded in whatever it is both factors measure, and therefore, neither factor compared with the other provides a clearly superior window onto attentional processes. Second, compared with either of the WAIS factors, the sustained attentional measures were more closely related to signs, and that relation could not be easily covaried away when WAIS IQ was controlled. Third, the laboratory measures of sustained attention were better able to account for the relation between the signs and school achievement variables than were the WAIS factors.

If soft signs are linked to deficits in sustained attention, as well as other aspects of cognitive functioning, it would be expected that signs would be connected to lower levels of school achievement in the adolescents. Partial correlational and multiple regression analyses indicated that the relation of signs to reading, spelling, and mathematics can be explained in terms of two types of impairment associated with signs, diminished capacity to sustain attention and, to some extent, more global deficits in cognitive functioning.

It might be argued that rather than low IQ causing poor achievement, poor achievement results in low IQ. Such an explanation is plausible; however, it is not supported by the data. IQ shows moderate across-age consistency. Schonfeld et al. (1988) found that age 17 IQ was moderately related to IQ assessed at ages 4 ($r = .50, p < .001$) and 7 ($r = .66, p < .001$), well before, or at the time of, entry into school. It might also be argued that poor achievement leads to difficulties in sustaining attention. It is, however, difficult to explain how lower achievement might bear on the adolescents' performance on the laboratory attention measures that, at a phenotypic level, differ considerably from the types of activities in which students engage in school. Modest, indirect evidence suggests that a causal path from poor achievement to inattention is unlikely. Although no laboratory measures of sustained attention were administered at age 7, moderate continuity in the subtests of the Wechsler scales thought to measure concentration (Kaufman, 1982) was found: for age 7 coding and age 17 digit symbol, $r = .33$, $p < .001$; for age 7 and age 17 digit span, $r = .53, p < .001$. Thus, the data are most compatible with the view that the relation between signs and reading and math achievement test performance is mediated by sustained attention.

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