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Uncoupling of Reading and IQ Over Time: Empirical Evidence for a Definition of Dyslexia

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Abstract

Developmental dyslexia is defined as an unexpected difficulty in reading in individuals who otherwise possess the intelligence and motivation considered necessary for fluent reading, and who also have had reasonable reading instruction. Identifying factors associated with normative and impaired reading development has implications for diagnosis, intervention, and prevention. We show that in typical readers, reading and IQ development are dynamically linked over time. Such mutual interrelationships are not perceptible in dyslexic readers, which suggests that reading and cognition develop more independently in these individuals. To our knowledge, these findings provide the first empirical demonstration of a coupling between cognition and reading in typical readers and a developmental uncoupling between cognition and reading in dyslexic readers. This uncoupling was the core concept of the initial description of dyslexia and remains the focus of the current definitional model of this learning disability.

Keywords

reading development, dyslexia, longitudinal methodology, dynamic modeling

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The ability to read shows large variability across children and adolescents, who range from highly proficient, fluent readers to inaccurate and slow readers (S.E. Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992). Early postulations suggested that reading achievement in the population can be described by a bimodal distribution that includes both normal achievement and reading disability (Rutter & Yule 1975). More recent evidence, however, points to a unimodal distribution in which reading disability is part of the lower tail (S.E. Shaywitz et al., 1992). Identifying the mechanisms that underlie differences in reading development is of primary importance not only for cognitive psychologists and neuroscientists, but also for clinicians and educators who are asked to evaluate and teach children experiencing reading difficulties. Understanding why reading skills develop differently across individuals is particularly important for the lower tail of the reading distribution, as poor performance may become disabling, interfering with academic progress in school (Perie, Grigg, & Donahue, 2005) and enjoyment of literacy-based activities, and giving rise to lifelong low self-esteem and anxiety (Raskind, Goldberg, Higgins, & Herman, 1999; S.E. Shaywitz, 1996, 2003; Sum, 1999; Sum, Kirsch, & Yamamoto, 2004). In this article, we examine one potential mechanism associated with differences in development of reading ability: the interrelations between reading achievement and cognitive ability over time.

Dyslexia, or specific reading disability, is defined as an unexpected difficulty in reading in relation to cognitive ability, education, or professional status (Lyon, 1995; Lyon, Shaywitz, & Shaywitz, 2003; S.E. Shaywitz, 1996, 1998; S.E. Shaywitz & Shaywitz, 2008). It is estimated to have a prevalence of 5% to 17% among school-age children (S.E. Shaywitz, 1998). One factor typically associated with differences in reading development and reading disabilities is IQ (B.A. Shaywitz et al., 1995; Ferrer et al., 2007; Stanovich, 1986). Although cognitive ability and reading processes both unfold over time, it is not known how these processes are interrelated over time or whether such interrelationships might explain variations in the development of reading proficiency. Such dynamics are potentially informative because of the interconnection between cognitive abilities and reading achievement, both theoretically

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(Cattell, 1971, 1987; Stanovich, 1986, 1991) and empirically (Ferrer & McArdle, 2004; Ferrer et al., 2007).

In previous research (Ferrer & McArdle, 2004), we found a strong association between the development of cognitive ability and changes in academic achievement (i.e., academic knowledge and quantitative abilities) during childhood and adolescence. We described these interconnections as coupled developmental sequences in which levels of one variable were positively related to changes in time in the other variable. Of particular relevance, we found evidence for a strong coupling over time between cognitive abilities (i.e., Full Scale, Nonverbal, and Verbal IQ on the Wechsler Intelligence Scale for Children–Revised, or WISC-R) and reading (i.e., Letter-Word Identification, Word Attack, and Passage Comprehension reading scales from the Woodcock-Johnson Psycho-Educational Battery, or WJ) for individuals in Grades 1 to 12 (Ferrer et al., 2007). Such couplings represented influences from, for example, cognition in a given year to positive changes in reading the following year. Results from those analyses indicated that (a) there was a positive dynamic relation between reading and cognitive ability from Grades 1 to 12; (b) this dynamic relation was symbiotic, with each process influencing the other over time; and (c) the mutual dynamics of reading and cognition appeared to be strongest during Grades 1 to 3, less strong during 4th to 8th grade, and weakest from 9th to 12th grade. Studies of adults, too, have found that cognitive ability (Verbal IQ) predicts reading accuracy (Berninger, Abbott, Thomson, & Raskind, 2001).

These findings suggest that the dynamic link between cognitive abilities and reading might underlie differences in reading development. Given this evidence, we wanted to evaluate the hypothesis that cognition-reading dynamics vary across levels of reading proficiency. In particular, we addressed two main questions in this study: (a) Are there differences in the dynamic interrelations of cognition and reading over time between individuals who follow a typical reading developmental pathway and those with reading disability? (b) Are there differences in these dynamics between impaired readers who compensate, eventually achieving proficient levels of reading accuracy and comprehension, and impaired readers who manifest persistent reading difficulties?

Method

Participants

The analyses we present here involve data from the Connecticut Longitudinal Study, a project involving a sample survey of Connecticut schoolchildren representative of those children entering public kindergarten in Connecticut in 1983. All subjects were children whose primary language was English. This cohort, assembled from a two-stage probability-sample survey, was followed longitudinally with the purpose of studying reading, learning, and attention (B.A. Shaywitz et al., 1995; S.E. Shaywitz et al., 1992, 1999; S.E. Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). The individuals in the sample ($N = 232$; 55.2% females and 44.8% males) were first assessed in 1st grade and were given individualized tests of cognitive abilities and achievement annually up through 12th grade. The sample contained Caucasians (84.3%), African Americans (11.2%), Asians (0.9%), Hispanics (2.0%), and children with unknown ethnicity (1.6%). The racial and ethnic composition of this sample from Connecticut was similar to that of the nation at the time of the study (U.S. Bureau of the Census, 1985).

Three groups of readers were identified on the basis of their reading scores in Grade 2 or 4 and in Grade 9 or 10. Reading deficiency was evaluated using the Reading Cluster score (the composite of all three reading subtests—see the next section) from the WJ (Woodcock & Johnson, 1977) and the WISC-R (Wechsler, 1981) Full Scale IQ score. At each grade, poor readers were identified as children with an observed WJ composite reading score 1.5 standard errors below the score predicted from their Full Scale IQ (discrepancy definition) or with a Reading Cluster score below 90 (low-achievement definition). Both of these definitions validly identify children as poor readers, and there is little evidence of differences between subgroups of children formed with one criterion versus the other (B.A. Shaywitz, Fletcher, Holahan, & Shaywitz, 1992; S.E. Shaywitz et al., 2003). The children in the sample were classified into three groups: *Typical* readers ($n = 142$) did not meet criteria for poor reading at either of the two assessments and had reading standard scores greater than 94 (above the 40th percentile; we adopted this criterion to prevent overlap with the other groups), *compensated* readers ($n = 28$) met criteria for poor reading in 2nd or 4th grade but not in Grade 9 or 10, and *persistently poor* readers ($n = 62$) met criteria for poor reading at both assessments.

Measures

Three subtests from the WJ were used for our composite reading score: Letter-Word Identification, Word Attack, and Passage Comprehension. These subtests were administered annually from 1st to 12th grade. In addition, participants were assessed on the WISC in Grades 1, 3, 5, 7, and 9. Tables 1 and 2 present the mean WJ reading scores and Full Scale IQs (along with standard deviations and sample sizes) for the three groups (in raw and z scores, respectively).[1] These means differed across groups, both at the initial assessment and throughout the grades. As indicated by the sample sizes, attrition was remarkably low, especially considering the large developmental span of the study, and was at similar low levels across groups.

Figure 1 depicts individual composite reading scores as a function of age for a randomly selected subsample ($n = 80$). Each line represents the trajectory for one individual (in z scores calculated using means and standard deviations from the first measurement occasion). It is clear from the graph that the groups differed in their reading trajectories. For example,

Table 1. Mean Reading and IQ Scores of the Three Groups: Raw Scores

	Reading composite									Full Scale IQ								
	Typical readers			Compensated readers			Poor readers			Typical readers			Compensated readers			Poor readers		
Grade	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
1	14.45	3.76	142	7.68	2.86	28	5.81	3.18	62	15.47	2.05	140	14.22	2.28	28	12.97	3.72	59
2	20.33	3.09	141	11.93	2.68	28	10.35	4.33	62									
3	22.92	2.33	141	17.23	2.83	28	13.78	3.54	62	20.13	2.20	141	19.69	2.64	27	17.28	3.56	62
4	25.14	2.09	142	19.94	2.71	28	16.41	3.57	62									
5	26.53	1.87	142	22.33	2.68	28	18.31	3.50	62	25.72	2.35	141	24.74	3.04	27	21.87	4.20	60
6	28.05	1.80	142	23.30	2.61	28	19.78	3.41	62									
7	29.10	1.48	141	25.06	2.43	28	21.26	3.27	62	29.53	2.56	140	28.34	2.98	28	25.36	3.97	60
8	29.79	1.55	140	26.44	2.45	28	22.20	3.43	61									
9	30.62	1.29	142	27.68	1.79	28	23.10	3.40	62	32.32	2.54	142	31.06	2.91	28	28.26	4.29	61
10	31.06	1.26	139	28.18	1.60	27	23.76	3.61	59									
11	31.39	1.36	138	28.81	1.94	27	24.16	3.62	60									
12	32.52	1.24	139	30.23	2.07	27	25.81	3.79	61									

Note: Reading scores are composite scores from the Woodcock-Johnson Psycho-Educational Test Battery (Woodcock & Johnson, 1977). IQ scores are from the Wechsler Intelligence Scale for Children–Revised (Wechsler, 1981). Three groups of readers were tested: typical readers, compensated readers (i.e., those whose accuracy improved), and persistently poor readers. IQ was measured in Grades 1, 3, 5, 7, and 9 only.

Table 2. Mean Reading and IQ Scores of the Three Groups: z Scores

	Reading composite									Full Scale IQ								
	Typical readers			Compensated readers			Poor readers			Typical readers			Compensated readers			Poor readers		
Grade	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*
1	0.568	0.749	142	–0.775	0.577	28	–1.15	0.636	62	0.224	0.715	140	–0.216	0.806	28	–0.619	1.29	59
2	1.74	0.616	141	0.068	0.540	28	–0.245	0.644	62									
3	2.24	0.463	141	1.12	0.570	28	0.435	0.707	62	1.83	0.763	141	1.63	0.899	27	0.848	1.25	62
4	2.69	0.416	142	1.66	0.548	28	0.957	0.714	62									
5	2.96	0.373	142	2.13	0.540	28	1.33	0.699	62	3.77	0.821	141	3.47	1.08	27	2.42	1.49	60
6	3.27	0.358	142	2.32	0.527	28	1.63	0.681	62									
7	3.47	0.292	141	2.67	0.492	28	1.92	0.654	62	5.10	0.892	140	4.68	1.05	28	3.71	1.36	60
8	3.62	0.307	140	2.95	0.495	28	2.11	0.691	61									
9	3.78	0.257	142	3.19	0.361	28	2.28	0.680	62	6.07	0.884	142	5.62	1.03	28	4.65	1.51	61
10	3.87	0.248	139	3.30	0.326	27	2.44	0.702	59									
11	3.93	0.269	138	3.42	0.400	27	2.48	0.731	60									
12	4.15	0.247	139	3.72	0.405	27	2.86	0.705	61									

Note: All values are based on z scores computed using means and standard deviations from Time 1. Reading scores are composite scores from the Woodcock-Johnson Psycho-Educational Test Battery (Woodcock & Johnson, 1977). IQ scores are from the Wechsler Intelligence Scale for Children–Revised (Wechsler, 1981). Three groups of readers were tested: typical readers, compensated readers (i.e., those whose accuracy improved), and persistently poor readers. IQ was measured in Grades 1, 3, 5, 7, and 9 only.

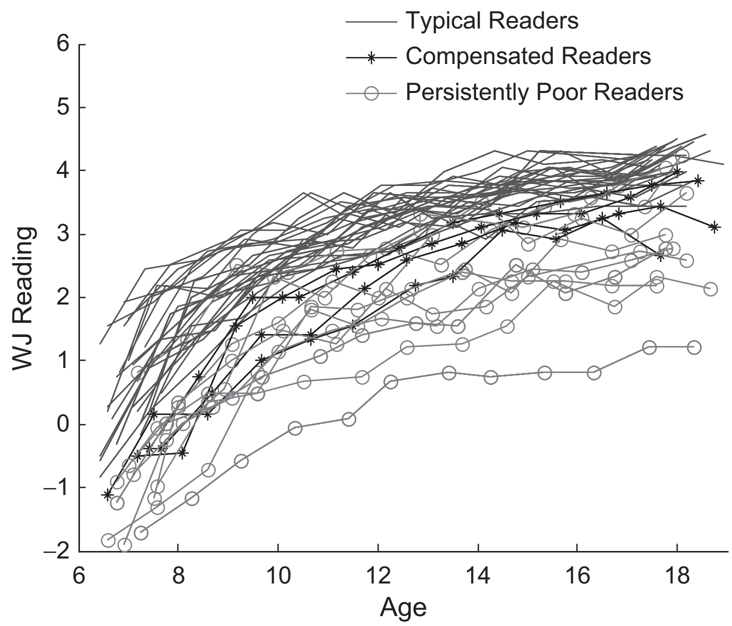

Fig. 1. Individual longitudinal plots of composite reading scores on the Woodcock-Johnson (WJ) test battery, for a subsample of individuals in the three reading groups.

typical readers started at a high level and followed curves that remained at higher trajectories than those of individuals in the two other groups. Moreover, the trajectories for this group were very homogeneous; they showed some variability during early childhood, but converged to a reduced range of scores in late adolescence. Individuals in the persistently poor reading group, in contrast, started with much lower scores and followed lower trajectories throughout childhood and adolescence; over time, they showed increasing variability, as well as increasing distance from the two other groups. Individuals in the compensated group also started at low levels, but their trajectories ended up at higher levels than those of the persistently poor readers.

Statistical models

To examine hypotheses regarding interrelations between cognition and reading over time, we used dynamic models based on latent difference scores (LDSs). In this section, we present some basic characteristics of these models. Further details about them are available elsewhere (mathematical and statistical properties—McArdle, 2001; McArdle & Hamagami, 2001; comparisons with other models of change—Ferrer & McArdle, 2003; applications to developmental data—Ferrer & McArdle, 2004). (In a previous study, we also used LDS models to examine the same data used in the present study; see Ferrer et al., 2007.)

According to LDS models, the trajectory equation for each observed variable (*Y* and *X*) at time *t* can be written as a function of an initial latent score (y_0 and x_0) and a linear accumulation of the latent changes (Δ_y and Δ_x) up to time *t* plus some residual (e_y and e_x):

$$Y_{it} = y_{i0} + \left(\sum_{k=1}^{t} \Delta_{yki}\right) + e_{yit} \tag{1}$$

$$X_{it} = x_{i0} + \left(\sum_{k=1}^{t} \Delta_{xki}\right) + e_{xit}. \tag{2}$$

The latent changes (Δ_y and Δ_x), in turn, can be expressed as a function of several components:

$$\Delta y_{it} = \alpha_y \cdot y_{is} + \beta_y \cdot y_{it-1} + \gamma_y \cdot x_{it-1} + \zeta_{\Delta yit} \tag{3}$$

$$\Delta x_{it} = \alpha_x \cdot x_{is} + \beta_x \cdot x_{it-1} + \gamma_x \cdot y_{it-1} + \zeta_{\Delta xit}, \tag{4}$$

where α is the coefficient associated with the slopes y_{is} and x_{is}; β is a self-feedback parameter representing the influence of the same variable at the previous state; γ is the coupling coefficient, representing the influence of the other variable at the previous state; and ζ_Δ represents the unexplained portion in the changes. Thus, according to this model, change in the true scores for each variable (Δy_t and Δx_t) is a function of three components: (a) a constant slope, α; (b) the scores on the same variable at the previous occasion, β; and (c) the scores on the other variable at the previous occasion, γ. This last component, the coupling parameter, represents forces from one variable at time *t* that lead to changes in the other variable at the next occasion, $t + 1$, as the system unfolds over time.

Table 3. Estimates From Bivariate Dynamic Models of the Reading-IQ Relationship in the Three Groups

Parameter	Typical readers (n = 142)		Compensated readers (n = 28)		Persistently poor readers (n = 62)	
	Reading	IQ	Reading	IQ	Reading	IQ
Initial mean score, μ_0	0.57*	0.22*	–0.81†	–0.24$^{n.s.,†}$	–1.15	–0.66
Linear growth slope, μ	1.41	0.55	0.79	1.07	0.58	0.83
Self-feedback, β	–.549	–.274	–.354	–.223	–.334	–.146
Coupling, γ	.130*	.401*	.090†	.182$^{n.s.}$	.075	.132$^{n.s.}$
Variance in initial scores, σ_0^2	0.540	0.436	0.296	0.577	0.372	1.42
Slope variance, σ_s^2	0.014	0.043	0.008$^{n.s.}$	0.028$^{n.s.}$	0.030	0.023$^{n.s.}$
Error variance, σ_e^2	0.025	0.101	0.046	0.133	0.051	0.173
Residual change variance, σ_Δ^2	0.026	0.043	0.046	0.036$^{n.s.}$	0.030	0.047$^{n.s.}$

Note: All parameters are full maximum likelihood estimates. Number of data points = 7,565. The superscript "n.s." indicates that a parameter's 95% bootstrap confidence interval contains zero. Asterisks indicate a significant contrast between the typical readers and the two dyslexic groups; daggers indicate a significant difference between the compensated readers and the persistently poor readers. The goodness of fit of the model to the data was measured using the chi-square statistic (χ^2 = 1,018, df = 441) and the Akaike information criterion (3,295). This overall chi-square was distributed across groups as follows (with percentage of the overall chi-square in parentheses)—typical readers: 539 (53%); compensated readers: 270 (27%); persistently poor readers: 209 (20%).

Results

Dynamics of cognition and reading in the three reading groups

Table 3 presents results from analyses examining the dynamics of reading and IQ over time in the three groups of readers. Initially (i.e., in Grade 1), typical readers had above-average reading and IQ means ($\mu_{read\text{-}0}$ = 0.57; $\mu_{IQ\text{-}0}$ = 0.22), and showed substantial variation across individuals ($\sigma^2_{read\text{-}0}$ = 0.540; $\sigma^2_{IQ\text{-}0}$ = 0.436). The dynamic estimates indicated that yearly changes (from 1st to 12th grade) in both variables were a function of (a) a positive constant slope ($\mu_{read\text{-}s}$ = 1.41; $\mu_{IQ\text{-}s}$ = 0.55) with small variability ($\sigma^2_{read\text{-}s}$ = 0.014; $\sigma^2_{IQ\text{-}s}$ = 0.043); (b) some inertia (β_{read} = –.549; β_{IQ} = –.274), representing a proportional effect of a variable's previous value on its changes at the next occasion (negative valence avoided indefinite growth near asymptotic values); and (c) a coupling parameter, representing the influence from the other variable at the previous year (γ_{read} = .130; γ_{IQ} = .401). These coupling parameters were both positive, indicating a mutual relationship between reading and IQ over time.

The estimates for the compensated and persistently poor dyslexic readers showed substantial differences from those for the typical group. Both dyslexic groups had significantly lower initial scores than the typical group did, especially in reading ($\mu_{read\text{-}0}$ = –0.81 and –1.15 for compensated and persistently poor readers, respectively); in addition, the compensated and persistently poor readers differed significantly in their initial reading scores. Over time, the influence of IQ on reading for these groups was small and significantly different from the influence observed in the typical group (γ_{read} = .090 and .075); again, these values differed significantly between the two dyslexic groups. The influence from reading to cognition, however, was not different from zero ($\gamma_{IQ} \approx 0$) in either group. Reading and IQ appeared to be less interrelated over time in these groups, unlike among the typical readers. Alternative models that constrained means, slopes, or coupling parameters to be equal across groups were rejected because they yielded significantly worse fit.

Developmental trajectories for the typical, compensated, and persistently poor readers

Figure 2 depicts the trajectories of reading for the three groups based on the model results. These trajectories match the observed data quite well (see Fig. 1). These predicted trajectories show the large difference between initial reading levels of the typical readers and of the two dyslexic groups, as well as the divergence of curves between the compensated and persistently poor dyslexic readers over time. To further inspect the dynamics of the relation between IQ and reading, we plotted vector fields for each of the groups (see Fig. 3). These fields represent the projections in time (i.e., yearly changes) for different combinations of scores. That is, for a given pair of reading and IQ scores, the arrows indicate the expected changes in both reading and IQ at the next measurement occasion. The direction of the arrows in relation to the y- and

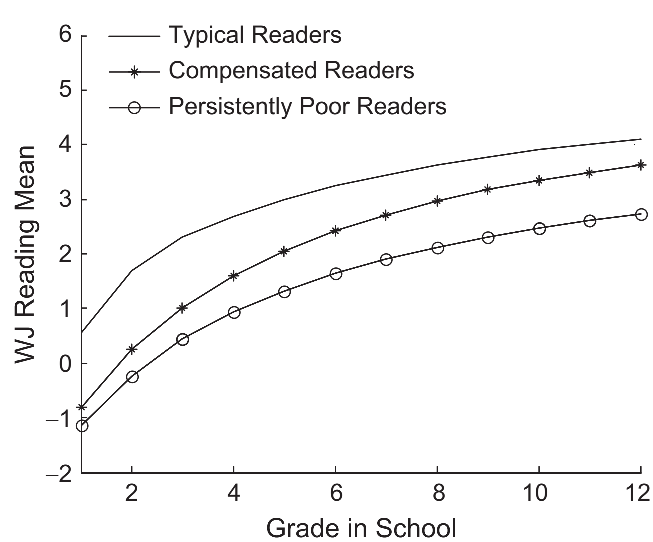

Fig. 2. Predicted trajectories for reading scores on the Woodcock-Johnson (WJ) battery across grades, separately for each of the three reading groups.

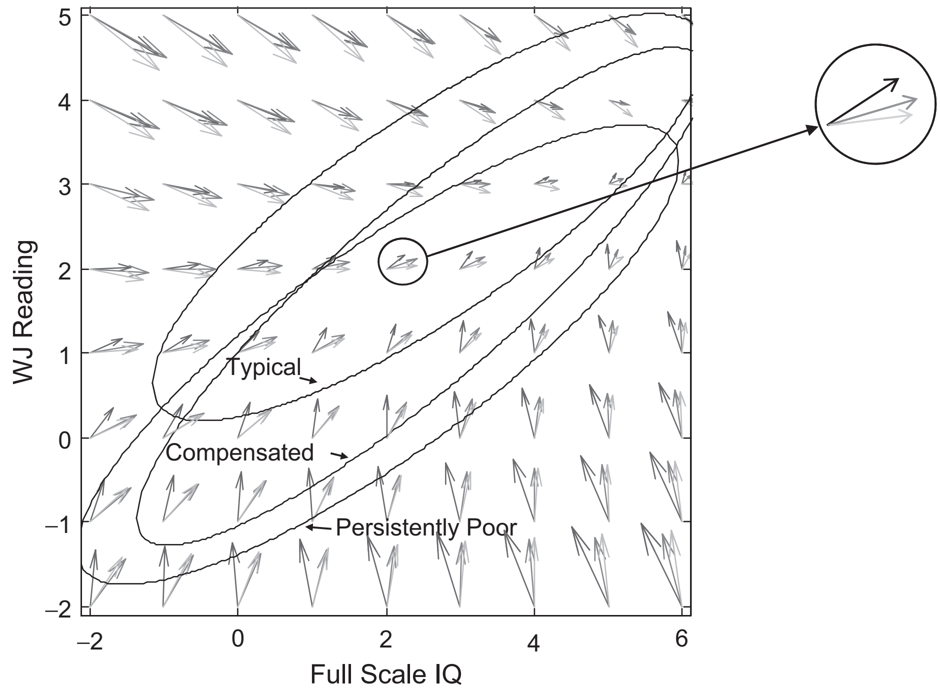

Fig. 3. Vector fields illustrating the reading-IQ dynamic systems in the three reading groups. These vector fields represent the direction of expected yearly changes in both reading and cognition as a function of concurrent states of both variables. Each arrow from a given point represents the prediction for a different reading group. For example, the blowup shows the predicted direction of changes for individuals with *z* scores of 2 on the Woodcock-Johnson (WJ) battery and 2 on the Wechsler Intelligence Scale for Children (Full Scale IQ); although individuals in all three groups are predicted to show an increase in both IQ and reading ability the following year, the predicted increase in reading ability is greatest for the typical readers (i.e., the most upward arrow) and smallest for the persistently poor readers (i.e., the most horizontal arrow). The ellipsoids demark the location of 95% of the data for each reading group.

x-axes indicate whether the expected changes are positive, negative, or neutral for each variable. The ellipsoids, which mark the location of 95% of the data, indicate large differences in the location of the scores across the groups. Typical readers showed a substantial concentration of high scores (z scores ≥ 4) for both reading and IQ. In contrast, compensated and persistently poor dyslexic readers showed a sizable density of low scores (z scores ≤ 0) for both reading and IQ.

As Figure 3 shows, given a similar pair of reading and cognition scores, members of different groups are predicted to develop differently over the following year. Typical readers are predicted to exhibit the greatest changes in both variables, and persistently poor readers are expected to exhibit the smallest changes in both variables.

Differences between compensated and persistently poor readers

To test the second hypothesis, we examined IQ-reading dynamics in the compensated and persistently poor readers. Individuals in the persistently poor group had significantly lower reading and cognition scores in first grade than did the compensated dyslexic readers (see Table 3). Similarly, persistently poor readers had lower slopes for both variables than the compensated group, and this difference in slope contributed in a uniform way to the differences in trajectories over time between these two groups. Both groups had weak couplings from IQ to reading and imperceptible effects (i.e., couplings not different from zero) from reading to IQ. However, the coupling from IQ to reading was significantly larger for the compensated dyslexic group than for the persistently poor group. Analyses using the specific WJ reading scales indicated a similar pattern of results regardless of the specific scale, with Letter-Word Identification and Passage Comprehension yielding very similar results, and Word Attack yielding the largest differences across the groups.

Figure 4 illustrates the effect of these dynamic influences on the predicted reading trajectories, depicting reading curves for both groups given different coupling values. The middle line in each panel represents the predicted curve based on the obtained coupling estimate. The lines above and below represent expected curves for couplings with values ±.1 and ±.2 from the observed estimates. Small increments in the couplings lead to steeply growing trajectories, whereas small decreases (i.e., approaching zero) result in flat curves. This figure illustrates the beneficial effect of mutual influences between reading and IQ on reading trajectories, as well as the differential effect of such influences across groups. For all couplings, the predicted reading trajectories for the compensated group are higher than those for the persistently poor group.

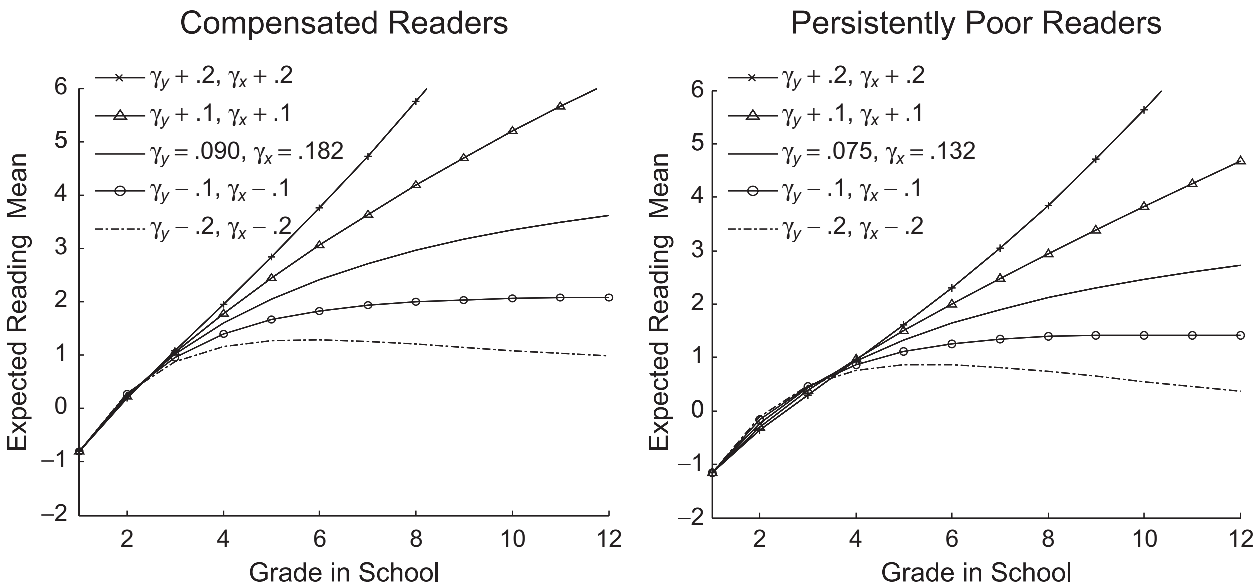

Fig. 4. Predicted trajectories for reading as a function of dynamic couplings between reading and cognition. In each panel, the middle line represents the predicted curve based on the obtained coupling estimate (γ), and the lines above and below represent expected curves for couplings with values $\pm.1$ and $\pm.2$ from the observed estimates. Trajectories for compensated readers are shown on the left, and trajectories for persistently poor readers are shown on the right.

Discussion

Our findings indicate that dynamic interrelations between reading and IQ over time account for differences in reading development. For typical readers, reading and IQ show bidirectional influences, whereas for both compensated and persistently poor dyslexic readers, these influences are smaller (from IQ to reading) or imperceptible (from reading to IQ). These differences in dynamics amplify discrepancies in scores at first grade and lead to distinct trajectories over time. One possible explanation for these differences is that dyslexics read less than typical readers and consequently acquire less vocabulary and general world knowledge from reading. Dyslexic readers' intellectual development may depend more on environmental inputs other than text.[2] According to this argument, reading would have a weaker relation to changes in IQ among dyslexics than among typical readers. Moreover, dyslexic readers' developing intelligence would seek stimulation in domains other than reading. In typical readers, there is a positive, reciprocal feedback loop between reading and IQ. In dyslexic readers, there is likely a positive, reciprocal feedback loop that involves factors not studied here and IQ.

Our results also suggest that dyslexic readers are characterized by a disruption in the interconnection between IQ and reading over time. These findings offer a somber picture for some individuals whose poor reading skills put them at a disadvantage by first grade. Moreover, these individuals seem to lack a mechanism for the close coupling of their overall cognitive and reading development over time or, alternatively, have an obstacle that prevents such a coupling. Despite such disadvantages, some of the dyslexic readers in our study (those in the compensated group) managed to achieve relatively accurate reading levels and Passage Comprehension scores comparable to those of typical readers by the time they became adolescents; however, they were not fluent readers. In our sample, this was a small and somewhat homogeneous group. Notably, although the initial reading scores for these children were very low, their cognitive ability was not as low. Over time, these individuals developed uniform reading trajectories. In contrast, persistently poor readers failed to become accurate readers and showed substantial variability in their trajectories. In addition to having the lowest reading skill and cognitive ability at first grade, this group exhibited individual differences that became accentuated across grades.

This pattern has been referred to as the Matthew effect (Merton, 1968; Stanovich, 1986): Those individuals who start at low levels of a variable fall even further behind over time, so that the gap between groups widens. Despite the intuitive appeal of a Matthew effect in dyslexia, it has been difficult to establish. The current data provide empirical evidence that such a gap may, indeed, be accentuated over time in persistently poor readers. Matthew effects have also been used to explain the widening impact of an early reading problem across time. Supporting such effects in dyslexia (and other language disorders), many studies have found longitudinal declines in verbal, and sometimes performance, IQ in these populations. In the current study, the group differences in both IQ and reading between dyslexic and typical readers increased over time. Reading less (and less well) not only may negatively affect reading development, but also may negatively influence language and IQ development.

The described differences between compensated and persistently poor readers reveal the important role of cognitive skills, which may provide sufficient scaffolding to allow some initially poor readers to eventually improve in their reading accuracy and comprehension. Our findings suggest the potential benefits of early intervention and reading programs that not only emphasize phonological skills, but also include other components that influence the impact of dyslexia, for example, semantic knowledge (Snowling, 2000) and visual memory (Campbell & Butterworth, 1985). The development of these skills, together with initial high cognitive ability, may help initially poor readers to decipher words they are unable to sound out, commit them to memory, and better comprehend what they are reading.

Our analyses underscored the interplay between reading and cognition from childhood through adolescence, examining their mutual influences, as well as possible differences in such effects across groups of readers. We used dynamic models that expressed reading and cognition as two processes in a coupled system and focused on changes in both variables, as well as their interrelationship over time (Ferrer & McArdle, 2004; Ferrer et al., 2007). Three points related to our approach deserve mention. First, the between-group differences in initial scores and dynamics (see Table 3) may seem to be related to our criteria for classifying the groups. We note, however, that the initial scores were obtained in first grade, 1 or 3 years before the first of the two assessments used for group classification. More important, the reading-IQ dynamics, which were the primary focus of our analyses, were estimated across all measurement occasions, representing interrelations between reading and IQ from childhood through adolescence. They are not related to the definition of the groups. Our dynamic models included latent change equations representing how two processes interrelated over time. These temporal interrelations—or developmental sequences—were independent of static scores or bivariate correlations at any given time. As illustrated in Figure 4, small changes in such lead-lag sequences can lead to large differences in the trajectories, and such trajectories cannot be predicted from invariant correlation matrices among groups. Furthermore, participants did not receive any special treatment as a result of their group assignment, which could have altered the dynamics differently across groups.[3]

The second point concerns the type of model we used. As detailed elsewhere (Ferrer & McArdle, 2003, McArdle, 2001; McArdle & Hamagami, 2001), LDS models are not the same as cross-lagged regression models or bivariate growth curves (or the equivalent multilevel models). The coupling parameters in our dynamic approach represent the relation between one variable and changes in the other variable over time, thus capturing possible developmental sequences. The third point concerns the size of the groups, especially the compensated and persistently poor groups. To examine the robustness of the estimates in relation to the sample sizes, we conducted bootstrapping analyses on the described model with 500 replications. The results from these analyses reproduced the original results. Moreover, the density of data relative to the number of estimated parameters was high. The number of available data points was 2,409, 476, and 1,054 for the typical, compensated, and poor readers, respectively. Given the number of estimated parameters (i.e., 23 per group), this data density was not insufficient.

Our findings have important implications for understanding of reading difficulties and developmental dyslexia. Since Morgan's (1896) initial description of Percy F., "a bright and intelligent boy" (p. 1378) who inexplicably struggled to read, the notion of an "unexpected" difficulty in learning to read has formed the core concept underlying developmental dyslexia. Lacking, however, have been empirical data demonstrating how such a dissociation between cognitive ability and reading might develop in children. Our findings of an uncoupling between IQ and reading, and the influence of this uncoupling on the developmental trajectory of reading, provide evidence to support the conceptual basis of dyslexia as an unexpected difficulty in reading in children who otherwise have the intelligence to learn to read. To our knowledge, this is the first empirical demonstration of the developmental uncoupling of reading and cognition that was the focus of the initial description of dyslexia and remains the focus of the current definitional model of this learning disability (Lyon et al., 2003; Morgan, 1896; S.E. Shaywitz, 1998).

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The authors declared that they had no conflicts of interests with respect to their authorship and/or the publication of this article.

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Notes

1. The raw data were rescaled to *z* scores based on means and standard deviations at Time 1. The purpose of this rescaling was to yield a common metric that would allow direct comparisons of scores for variables with different scales (i.e., WJ and WISC) and across ages.
2. We thank an anonymous reviewer for this plausible explanation.
3. To further examine this issue, we conducted a Monte Carlo study. The results of these simulations confirmed that the differences in the dynamics across the groups were not related to the selection criteria. Full details of this Monte Carlo study are available from the first author upon request.

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