

# IQ of four-year-olds who go on to develop dyslexia

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Do children who go on to develop dyslexia show normal verbal and nonverbal development before reading onset? According to the aptitude-achievement discrepancy model, dyslexia is defined as a discrepancy between intelligence and reading achievement. One of the underlying assumptions is that the general cognitive development of children who fail to learn to read has been normal. The current study tests this assumption. Additionally, we investigated whether possible IQ deficits are uniquely related to later reading or are also related to arithmetic. Four-year-olds ( $N = 212$ ) with and without familial risk for dyslexia were assessed on 10 IQ subtests. Reading and arithmetic skills were measured four years later, at the end of Grade 2. Relative to the controls, the at-risk group without dyslexia had subtle impairments only in the verbal domain, while the at-risk group with dyslexia lagged behind across IQ-tasks. Nonverbal IQ was associated with both reading and arithmetic, whereas verbal IQ was uniquely related to later reading. The children who went on to develop dyslexia performed relatively poorly in both verbal and nonverbal abilities at age 4, which challenges the discrepancy model. Furthermore, we discuss possible causal and epiphenomenal models explaining the links between early IQ and later reading.

**Keywords:** Arithmetic, dyslexia, familial risk, IQ, reading.

## **Introduction**

The first case reports of developmental dyslexia describe children who fail to master literacy despite normal development in other cognitive domains (e.g., Kerr, 1897; Morgan, 1896). Therefore, the reading problems they faced were unexpected within the context of their otherwise normal cognitive development. This ‘unexpectedness’ is translated into diagnostic criteria that take intelligence measures into account. According to the so-called aptitude-achievement discrepancy model, dyslexia is defined as a discrepancy between intelligence and reading achievement (Fletcher, Lyon, Fuchs, & Barnes, 2007). Although several researchers have advised against the use of IQ-scores in the diagnosis of learning disorders (e.g., Fletcher, Coulter, Reschly, & Vaughn, 2004; Siegel, 1989; Tannock, 2013), it is still commonly used.

One of the assumptions underlying a discrepancy model is that the general cognitive development of children who fail to learn to read has been normal. This assumption is rarely tested, however. After the start of reading, the assumption cannot be adequately examined because the development of verbal and nonverbal IQ of children with reading problems might have been adversely affected by less print exposure as a consequence of their poor reading (Cunningham & Stanovich, 1997). Hence, longitudinal studies that start before reading onset are required to investigate the issue of normal cognitive development.

There are several prospective studies assessing cognitive precursors of reading ability and disability, but these studies usually match groups of reading-disabled and typically-reading children on IQ (e.g., de Jong & van der Leij, 2003) and are therefore not suitable for the present purpose. A more appropriate design is to follow children at-familial risk of dyslexia, that is, children with dyslexic relatives. The current study

is a familial-risk study that reports verbal and nonverbal IQ-data of four-year-olds who went on to become dyslexic. Do these children indeed show normal cognitive development? To pursue this question these children were compared to children with and without a familial risk who did not develop dyslexia on nonverbal and verbal IQ (i.e., language skills).

In a landmark study, Scarborough (1990) compared at-risk children who later became dyslexic with control children. She found that the at-risk dyslexic children were deficient in several language skills from age 2½ onwards. Slow language development in the at-risk children with dyslexia was also shown by a prospective study of Snowling, Gallagher, and Frith (2003). When the children were about 4 years old, they had deficiencies in vocabulary, narrative skills, and verbal short-term memory. At this age, nonverbal IQ was not significantly lower, despite the observed medium effect size of .5. Yet at 6 years of age both verbal and nonverbal IQ of the dyslexic children were significantly lower than that of their peers without familial risk by more than one standard deviation. Furthermore, the at-risk children who did not become dyslexic showed at both measurement occasions normal nonverbal IQ, but they had a slightly lower verbal IQ than the children without familial risk. This latter difference had a medium effect size, but missed significance possibly due to a lack of power.

Recently, Torppa, Lyytinen, Erskine, Eklund, and Lyytinen (2010) examined very early language markers of dyslexia in a familial-risk study. Various receptive and expressive language abilities were examined in this group between 1½ and 5½ years of age. From age 2 onwards, the at-risk and non at-risk children who later became dyslexic showed impairments relative to the controls. At-risk children who became normal readers tended to show weak expressive syntax and vocabulary at age 5,

although this difference ( $d = .4$ ) was not significant. Torppa et al. also found that at age 2, the future dyslexic children had significantly lower full-scale IQ than the other two groups, with a medium effect size. At age 5 they performed significantly lower ( $d = 1$ ) than the control group on verbal IQ. However, at this age nonverbal IQ was similar in all groups.

Taken together, these studies show that children with dyslexia typically had problems with language acquisition in the preschool years. However, the findings in the few studies in which lags in nonverbal abilities were examined are less consistent. Snowling et al. (2003) found that children who later faced dyslexia performed slightly lower at age 4 and evidently lower at age 6. In contrast, the children with dyslexia in the study of Torppa et al. (2010) had normal nonverbal IQ before reading onset.

In the current study we compared at-risk dyslexic, at-risk non-dyslexic, and non-dyslexic control children without familial risk, on several subtests of verbal and nonverbal IQ when they were 4 years of age. In addition, we addressed two more issues. Firstly, whereas various abilities within the verbal domain have been considered, a differentiation among nonverbal abilities has not been made. In the current study different aspects of nonverbal IQ were examined. As a second issue, we considered whether the possibly lower IQ of children who go on to develop dyslexia specifically relates to their later reading difficulties, or whether their lower IQ is due to (subclinical) problems that are comorbid to dyslexia. We hypothesized that this could especially be true for a possible lower nonverbal IQ: in models of decoding, verbal abilities (e.g., the phonological lexicon in dual-route models or the semantic component in connectionist models) do explicitly play a part, whereas nonverbal abilities do not. Because dyslexia and dyscalculia often co-occur (Landerl & Moll, 2010), we chose to include arithmetic ability in the present study. In addition, basic

arithmetic skills are, besides basic reading skills, arguably the most important foundational skills acquired during the early school years.

## **Method**

### **Participants**

Three groups of children of the Dutch Dyslexia Programme (see van Bergen, de Jong, Plakas, Maassen, & van der Leij, 2012) were involved in this study. The at-risk dyslexic group consisted of 44 dyslexic children with a familial risk for dyslexia. The at-risk non-dyslexic group comprised 100 children with a familial risk but without dyslexia. Finally, the control group included 68 children without a familial risk and without dyslexia. Two children without a familial risk were categorized as dyslexic and were omitted from the study. All at-risk children had at least one parent and one close relative with dyslexia. On average, the scores of the dyslexic parents belonged to the bottom 5% on reading fluency. A detailed description of the assessment of familial risk is given in van Bergen et al. (2012). Informed consent was obtained from all parents. All children were native speakers of Dutch. All but one child attended mainstream education.

At the end of Grade 2, children were considered dyslexic when their score on the word-reading fluency task described below corresponded to the weakest 10% in the population (which translates to  $> 1.3 SD$  below the mean). At the *beginning* of Grade 2 almost all (93%) of these dyslexic children scored below the 25<sup>th</sup> percentile and 64% scored below the 10<sup>th</sup> percentile. Their IQ scores (at age 4) ranged from 73 to 129. In an earlier paper on the same sample we reported that the dyslexic children were impaired in reading accuracy and fluency, spelling, phonological awareness, and rapid naming (van Bergen et al., 2012). Thus, our group of children with dyslexia had

a family history of dyslexia and exhibited persistent reading impairment and a typical dyslexia profile. Operationalizing dyslexia based on low achievement (and  $IQ \geq 70$ ) rather than on IQ-achievement discrepancy is recommended by the DSM-5 working group (Tannock, 2013). Our low-achievement cutoff of 1.3 *SD* is in line with their recommendation of 1–1.5 *SD* for children at family risk (Tannock, 2013, p.14). We used reading fluency, not accuracy, to assess reading status, as is standard practice in Dutch and other transparent orthographies.

Table 1 presents characteristics of the three groups of children. Percentages of boys were similar across groups and age differences were not significant. Parental education was ranked on a scale ranging from 1 (*primary school only*) to 5 (*university degree*). Parental education (averaged over both parents) was lower in the at-risk than in the control group. Furthermore, the at-risk dyslexic group lagged behind on arithmetic (bottom Table 3).

## **Measures**

Measures were selected for nonverbal IQ (at age 4), verbal IQ (at age 4½), and school achievement (at age 8; end second grade). The reliabilities of the measures are listed in Table 3.

### **Nonverbal IQ**

The nonverbal-IQ test battery of Tellegen, Winkel, Wijnberg-Williams, and Laros (1998) is widely used in the Netherlands and Flanders because of its high psychometric quality (Evers, van Vliet-Mulder, & Groot, 2000). It was originally developed for deaf children; Hence, measures are genuinely nonverbal. For hearing children spoken language is used during assessment to create a natural situation, but the verbal instructions do not provide additional information. The test battery is composed of six subtests. The performance tasks (block design, patterns, and object

assembly) tap visual-spatial processing, visual-motor coordination, and persistence. Solutions can be obtained by trial-and-error. The reasoning tasks (picture completion, categories, and analogies) measure fluid reasoning about concrete and abstract categories. From the presented material a principle has to be detected and subsequently applied to new material.

Each subtest consists of two parts, with in total 14 to 17 items of increasing difficulty. In Part 1 of each subtest, the first few items are first demonstrated by the tester to show the requirements of the items. Part 2 of each subtest starts with an item for practice. The items in Part 2 of the Performance tests are stopped after 2'30 minutes for practical reasons. All test items are scored as either correct or incorrect. Following an incorrect response, the tester shows the correct solution so the child understands the purpose of the test without verbal explanation. Each subtest contains a discontinuation rule. Scaled subtest scores were derived from the manual. The scores combine to form a nonverbal-IQ score with a reliability of .90. Concerning validity, the nonverbal-IQ score correlates .78 with the British Abilities Scales and between .60 and .83 with the WPPSI-R and WISC-R. The six subtests are described below.

***Performance tests.***

*Block design.* The child arranges coloured squares according to a design depicted in a booklet. The difficulty increases from designs with only red coloured squares to designs with red, yellow, and red/yellow squares.

*Patterns.* The test involves copying abstract line patterns from a booklet. The child has to draw the patterns by connecting dots. It starts with simple patterns (e.g., connecting 2 dots) and increases to patterns that require connecting 4, 9, or 16 dots. Drawings are scored according to whether the right dots are connected, rather than manual dexterity.



*Object assembly.* The test requires the child to do jigsaw puzzles of three to six pieces. The puzzle images include familiar objects or animals. In Part 1 the puzzles come with the help of a picture and a frame to fit the puzzle in. In later items no frame and picture are provided.

***Reasoning tests.***

*Picture completion.* The child completes a set of pictures of which parts are missing. In the items in Part 1 four pictures are shown. Of each picture a part is missing (e.g., four different animals are depicted without legs). The missing parts are depicted on four cards. Part 2 consists of items depicting a scene (e.g., a boy in a kitchen) with one or two elements missing. The child completes the picture with the appropriate cards.

*Categories.* In this test the child has to detect the underlying concept of a set of pictures. The first part requires the child to sort cards in two semantic categories, like dolls and teddy bears. In the second part three pictures are shown that belong to the same semantic category (e.g., fruit). Out of five cards two have to be picked that also belong to this category.

*Analogies.* In Part 1, pieces have to be sorted in two small trays. The pieces differ on three dimensions: form (circles, squares, and triangles), colour (blue and red), and size (small and large). The booklet shows the sorting principle above the trays. In Part 2 the same changing principle as in the example analogy has to be applied. For instance, the example analogy depicts a small blue triangle that is transformed into a big blue triangle, meaning a change in the dimension size.

**Verbal IQ**

We selected the adapted and standardized Dutch version of the Reynell Developmental Language Scales (van Eldik, Schlichting, Iutje Spelberg, van der

Meulen, & van der Meulen, 2001) and three tests from a language-skill battery (Schlichting, van Eldik, Iutje Spelberg, van der Meulen, & van der Meulen, 2003). All items are scored as either correct or incorrect. Each subtest contains a discontinuation rule. Standard scores were derived from the manuals.

*Language comprehension.* The test assesses sentence comprehension. The sentences concern relations between objects and increase in complexity. The child has to show the meaning of the sentence using the objects provided, for example “Put the knife on the plate”. There are 87 items. The test’s reliability is .90.

*Expressive vocabulary.* The child is required to name pictured objects or to complete the description of a picture (e.g., “That are trains. This one is long and this one is...” [short]). In this way the knowledge of 62 nouns, verbs, adjectives, adverbs, and prepositions was assessed. The reliability is .90.

*Expressive syntax.* In this test syntactic structures are elicited using pictures and objects. In the first 12 items the child has to repeat a sentence literally. In later items a sentence needs to be repeated with a variation, or a sentence needs to be completed. The sentences are embedded in a short story. For example, the experimenter shows a picture of a man and a woman and two apples, and says “They are both going to eat an apple. This one is for him and ...” after which the child says: “this one is for her”. There are 40 items. The reliability is .86.

*Verbal short-term memory.* Children repeat series of one to six words. Words are one-syllabic concrete nouns. The test starts with a practice and a test item of one word. Subsequently, blocks of items increasing from two to five words are given. Each block consists of one practice and three test items. Finally, there are two 6-word items, adding up to 15 items. The reliability is .79.

### **School Achievement**

*Reading.* Word-reading fluency was assessed using a list comprising 150 monosyllabic words (Verhoeven, 1995). All words contain at least one consonant cluster. The score is the number of words read correctly within one minute. This test is widely used in Dutch education. Its reliability for this age is .96.

*Arithmetic.* Two subtests of the arithmetic tempo test (de Vos, 1992) were administered: addition and subtraction. Each subtest includes 40 problems of increasing difficulty. Per problem two operands have to be added or subtracted. All operands and outcomes are below 100. The score was the number of correctly solved problems within one minute. The reliability of each subtest is .93 (Stock, Desoete, & Roeyers, 2010). A total score was computed as the sum of the standard scores.

## **Procedure**

Testing lasted one hour at age 4, two hours at age 4½, and two hours at age 8. The tests at age 8 reported in this paper are part of a larger test battery (see van Bergen et al., 2012, for an overview and results). Tests were administered individually in a quiet room at university.

## **Results**

Group means on the IQ subtests are given in Table 2 and depicted in Figure 1 and 2. Table 3 gives the descriptive statistics of the reading and arithmetic measures. Correlations among all measures can be found in the Table 4. Distributions were approximately normal and missingness varied from 0 to 4%.

The results are presented in three sections. First, we consider the factor structure of the various verbal and nonverbal IQ tests. Next, we relate IQ at the age of 4 to reading and arithmetic achievement at the end of second grade. Finally, we examined differences in verbal and nonverbal IQ among at-risk dyslexic, at-risk non-dyslexic, and non-dyslexic control children without familial risk.

### **Structure of the IQ tests**

Confirmatory factor was used to test the hypothesised structure of the 10 IQ-subtests in the full sample. The analyses were conducted with Mplus (version 2.21, Muthén & Muthén, 2007) using maximum likelihood estimation. One latent variable was specified for verbal IQ (four indicators) and two for nonverbal IQ: a performance factor and a reasoning factor, each with three indicators. Allowing a correlated error between object assembly and categories, this model had an excellent fit:  $\chi^2(31, N=212) = 34.24, p = .315, RMSEA = .022$  [90% CI: .000-.058], SRMR = .037, CFI = .995. A two-group model with an at-risk and a non at-risk group also had an excellent fit and yielded virtually identical parameter estimates.

### **The relationship of IQ at age 4 and second-grade school achievement**

Structural equation modelling was used to examine a model of the relationship of the three IQ factors with later reading and arithmetic achievement. In this model, the three IQ factors were specified to load on one second-order factor, labelled IQ. Note that with three factors this second-order model is equivalent to the three-factor model that was examined in the previous section. Reading and arithmetic achievement were also specified to load (with equal factor loadings) on a common factor, labelled School Achievement. Finally, School Achievement was regressed on IQ.

The fit of this model was adequate:  $\chi^2(50, N=212) = 69.57, p = .035, RMSEA = .043$  [.012-.066], SRMR = .047, CFI = .974. However, the model fit was improved significantly by adding a direct effect from verbal IQ to reading ( $\Delta\chi^2(1) = 7.20, p = .007$ ). The final model (presented in Figure 3) provided a good fit to the data:  $\chi^2(49, N=212) = 62.37, p = .095, RMSEA = .036$  [.000-.060], SRMR = .043, CFI = .982. Note that the factor School Achievement reflects the variance that arithmetic and reading have in common. The significant extra path from verbal IQ to reading

indicates that verbal abilities predict unique variance in reading after differences in arithmetic have been controlled.

### **Differences among reading groups**

The at-risk dyslexic, at-risk non-dyslexic, and control children were compared on the three IQ factors (the verbal, performance and reasoning factors). To this end factor scores were derived on the basis of the three-factor model that adequately described the 10 IQ subtests (see above). Comparing the groups on factor scores rather than subtest scores is more reliable and reduces the number of statistical comparisons, which in turn reduces false positives. Descriptive statistics for the scores on the three factors are presented in Table 3. Differences among the groups on the three IQ factors were evaluated using one-way ANOVAs followed by two planned contrasts: at-risk dyslexic versus at-risk non-dyslexic, and at-risk non-dyslexic versus controls. Subsequently, the analyses were performed with arithmetic or parental education as covariate.

### **Nonverbal abilities**

Nonverbal abilities were subdivided into a performance and a reasoning factor, but the results were very similar. For both, the group effect was significant (performance factor:  $F(2, 209) = 6.54, p = .002$ ; reasoning factor:  $F(2, 209) = 6.22, p = .002$ ). The at-risk non-dyslexic group outperformed the at-risk dyslexic group (performance:  $F(1, 209) = 11.64, p = .001$ ; reasoning:  $F(1, 209) = 7.67, p = .006$ ), but did not significantly differ from the control group, (performance:  $F(1, 209) < 1$ ; reasoning:  $F(1, 209) = 1.15, p = .285$ ).

Next, we examined whether the lower nonverbal ability of the at-risk dyslexics was related to their later arithmetic difficulties (see bottom Table 3). Arithmetic as covariate controls for the variance in IQ that is related to arithmetic and that

arithmetic and reading have in common (similar to the model in Figure 3). In ANCOVAs, the group differences on both performance ( $F(2, 208) = 2.11, p = .124$ ) and reasoning ( $F(2, 208) = 2.18, p = .115$ ) disappeared, after controlling for arithmetic (performance:  $F(1, 208) = 13.46, p < .001$ ; reasoning:  $F(1, 208) = 8.75, p = .003$ ).

We also conducted ANCOVAs with parental education as covariate to test whether the lower performance of the at-risk dyslexic group could be due to a lower SES. The results for the two ANCOVAs were similar: Although the effect of parental education was significant (performance:  $F(1, 203) = 5.57, p = .019$ ; reasoning:  $F(1, 203) = 11.38, p = .001$ ), the group effect remained significant (performance:  $F(2, 203) = 5.39, p = .005$ ; reasoning:  $F(2, 203) = 3.64, p = .028$ ). Moreover, the follow-up contrast comparing the at-risk children with and without dyslexia remained significant (performance:  $F(1, 203) = 10.78, p = .001$ ; reasoning:  $F(1, 203) = 7.14, p = .008$ ).

### **Verbal abilities**

The ANOVA on the verbal-IQ factor revealed a group difference,  $F(2, 209) = 9.56, p < .001$ . The contrasts confirmed a stepwise pattern: the at-risk dyslexics scored lower than the at-risk non-dyslexics,  $F(1, 209) = 7.57, p = .006$ , who scored lower than the controls  $F(1, 209) = 4.90, p = .028$ .

In contrast to the nonverbal-IQ findings, the ANCOVA on verbal IQ with arithmetic as covariate showed that the effect of arithmetic was not significant,  $F(1, 208) = 1.85, p = .175$ , and that the effect of group ( $F(2, 208) = 6.17, p = .003$ ) and the two contrasts remained significant.

Finally, in an ANCOVA the effect of parental education was significant,  $F(1, 203) = 19.47, p < .001$ . Nevertheless, the overall group effect remained significant,  $F(2, 195) = 4.10, p = .018$ , as did the difference between the two at-risk groups,  $F(1, 203) = 6.45, p = .012$ . However, after controlling for parental education the significant

difference between the at-risk non-dyslexic and the control group disappeared,  $F(1, 195) < 1$ .

### **Discussion**

The current study examined the relationship between intelligence in four-year-olds and their reading status four years later in a sample of children with and without a familial background of dyslexia. We found that at-risk children who went on to be classified as dyslexic were impaired relative to control children (i.e., not at-risk and non-dyslexic) on both verbal and nonverbal IQ. The at-risk children who became normal readers showed slight but significantly poorer performance in the verbal, but not in the nonverbal domain. All reported deficits of the at-risk dyslexic children are relative to the other two groups rather than relative to norm scores. Our sample scored in general above average on IQ, probably due to the overrepresentation of parents with a high educational level (see van Bergen et al., 2012, p.33).

Given that reading and IQ are correlated, it might be regarded as obvious that a group of poor readers has a somewhat lower IQ than a group of normal readers. However, within an IQ-matched subsample of children with below-average full-scale IQ and with ( $n = 75$ ) and without ( $n = 26$ ) familial risk, 37% versus 8% of the children developed dyslexia. This difference demonstrates once more that low reading cannot be explained by low IQ alone.

The at-risk dyslexic children lagged behind across tests of verbal IQ. At 4 years old, the at-risk dyslexia group was characterized by relatively poor sentence comprehension, poor expressive syntax, weak vocabulary, and poor verbal short-term memory ( $d = .94$  on the factor score). This confirms previous reports of early oral-language deficits in dyslexic children (Scarborough, 1990; Snowling et al., 2003;

Torppa et al., 2010). These studies as well as the current one reported large effect sizes, suggesting that these findings are robust across orthographies.

The verbal IQ of the at-risk children who did not develop dyslexia were somewhat lower ( $d = .39$ ) relative to the controls. Previous studies (Snowling et al., 2003; Torppa et al., 2010) found similar effect sizes, although none of these effects reached significance. Generally, the at-risk non-dyslexic children perform slightly lower in the verbal domain, which may only be detectable in large samples.

Controlling for differences in parental education suggests that, relative to their peers without familial risk, the lower language skills of children at-risk might be attributable to their lower socioeconomic background. It could well be that the at-risk families offer a less rich language environment. However, Neiss and Rowe (2000) disentangled the environmental and genetic components underlying the correlation between parental education and children's verbal IQ. They estimated that the environmental effect of parental education explains no more than 4% of children's verbal IQ. As both children's IQ (Walker, Petrill, & Plomin, 2005) and parental education (Rowe, Vesterdal, & Rodgers, 1998) are for about two-thirds genetic in origin, the disappearance of the group effect in the ANCOVA might well be through 'controlling for' genetic rather than environmental differences between the groups. Indeed, the parents of the control children were somewhat better in verbal reasoning (van Bergen et al., 2012), a proxy for verbal IQ. However, an extra ANCOVA with parental verbal-reasoning as covariate<sup>7</sup> showed no significant effect of verbal reasoning, which favours the environmental explanation of SES' effect.

Interestingly, the at-risk dyslexic group also lagged behind on nonverbal IQ, although somewhat less than in the language domain. In line with Snowling et al.

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<sup>7</sup> Only scores of the weakest-reading parent were available. Details of this analysis can be obtained from the first author.



(2003), we found that around 4 years of age these children performed on average over half a standard deviation lower on nonverbal IQ than the controls. Nevertheless, this difference reached significance only in the present study due to the larger sample size. In contrast, Torppa et al. (2010) did not find differences on nonverbal IQ at age 5. Nevertheless, the present findings agree with both studies in that at-risk children who did not develop dyslexia had age-adequate nonverbal IQ.

At a more general level, we were interested in the nature of the link between IQ at age 4 and reading at age 8. Are the lower IQ's shown by the future dyslexics specifically related to reading or are they also related to another basic academic skill, arithmetic? Our results from structural equation modelling as well as ANCOVAs indicate that verbal IQ is specifically related to reading, not to arithmetic, which is expected in view of the linkage between the language and reading systems (Hayiou-Thomas, Harlaar, Dale, & Plomin, 2010). Yet, our observed unique relation between verbal IQ and reading does not elucidate whether they are independent consequences of shared aetiological factors or, alternatively, whether there is a causal link, with the developing reading system building on the language system.

In contrast to verbal IQ, we found that nonverbal IQ is related to both reading and arithmetic. This is in line with the generalist-genes hypothesis put forward by Kovas and Plomin (2007). Kovas, Haworth, Dale, and Plomin (2007) found that one-third of the genes that influence one academic domain are specific to that domain, one-third overlaps with other academic domains, and one-third overlaps with genes associated with IQ. For dyslexia, the identified candidate susceptibility genes are associated with anomalies in neuronal migration and axon growth (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006). In light of the deficiency in these fundamental processes, pleiotropic cognitive deficits are to be expected. This suggests

that the poor nonverbal IQ of the future dyslexics might well be epiphenomenal to poor reading, rather than causally linked.

In the current study we only assessed fairly basic school skills. Even higher predictive relations are expected between preschool IQ and later reading comprehension and mathematics. A limitation of the study is the lack of measures of attention or motor problems for example, since the groups might differ in this respect. Our study did, however, include measures of arithmetic problems, of which the findings highlighted the value of studying comorbidity. Finally, it should be noted that verbal IQ batteries (e.g., the WISC, Wechsler, 2004) usually also include verbal reasoning, besides vocabulary and verbal short-term memory measures. It is not entirely clear if and how the absence of a measure of verbal reasoning has affected our findings. If differences among the groups in verbal reasoning are relatively smaller, then inclusion of verbal reasoning would have resulted in somewhat smaller differences in verbal IQ. However, given the robust differences on the other verbal tests it is unlikely that this would have changed the overall pattern of differences among the groups. However, it is important that our results can be fully compared with those of other familial risk studies (see Introduction) in which verbal reasoning was not included either.

Our study is of interest for the debate on the diagnosis of dyslexia. The children with dyslexia already had a lower full-scale IQ before reading onset, arguably as part of their disorder. According to the aptitude-achievement discrepancy model these children need to have even more severe reading difficulties in order to be diagnosed as dyslexic. Since it is now more or less accepted that children with reading difficulties might have additional language difficulties, some scholars have proposed leaving verbal IQ out of the definition and instead using a discrepancy with nonverbal

IQ. However, the future dyslexic readers in our study also had lower nonverbal IQ. Our findings, together with evidence from earlier mentioned behavioural and molecular genetic studies, raise the possibility that dyslexia in itself affects brain circuits not related to reading. If so, then it seems undesirable to tap these circuits by IQ-tests and to take these IQ-scores into account in the diagnosis of dyslexia.

Our findings show that at the group level the children who went on to develop dyslexia performed relatively poorly in both verbal and nonverbal IQ at 4 years of age. Even though the mechanisms that might link these abilities to reading acquisition are not fully understood, our findings demonstrate that the cognitive development of the group of children who will fail to learn to read is atypical.

Table 1  
*Children's Characteristics by Group*

	At-risk		Control	<i>p</i>
	Dyslexic	Non-dyslexic		
Sample size	44	100	68	
No (%) of boys	27 <sub>a</sub> (61%)	57 <sub>a</sub> (57%)	41 <sub>a</sub> (60%)	.855
Age in months				
At nonverbal ability assessment	48.20 <sub>a</sub> (2.74)	47.68 <sub>a</sub> (3.02)	47.07 <sub>a</sub> (2.25)	.095
At verbal ability assessment	53.19 <sub>a</sub> (1.60)	53.01 <sub>a</sub> (1.45)	52.69 <sub>a</sub> (1.07)	.144
Parental education	3.33 <sub>a</sub> (0.86)	3.53 <sub>a</sub> (0.78)	4.17 <sub>b</sub> (0.72)	<.001

*Note.* The group means are given with standard deviations in parentheses. Numbers and means in the same row that do not share subscripts differ at  $p < .05$  on the  $\chi^2$ -test or Tukey's test. No = number.

Table 2  
*Children's Performance by Group on Raw IQ Scores*

	At-risk					
	Dyslexic		Non-dyslexic		Control	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Nonverbal ability (4 yr)						
Nonverbal IQ	105.56	15.87	113.55	14.31	113.87	15.24
Subtests						
Block design	10.55	2.71	12.28	3.02	11.87	3.14
Patterns	9.89	3.09	11.56	3.06	11.76	3.26
Object assembly	11.98	2.70	12.76	2.58	12.78	3.06
Picture completion	12.00	3.92	12.67	2.80	12.71	3.32
Categories	11.47	3.41	12.11	2.87	12.57	3.15
Analogies	11.64	2.69	12.47	2.80	12.63	2.94
Verbal ability (4½ yr)						
Language comprehension	103.98	10.81	109.60	12.34	113.43	10.49
Expressive vocabulary	102.52	14.87	107.39	14.34	110.68	13.31
Expressive syntax	104.90	12.83	109.25	12.87	113.10	12.47
Verbal short-term memory	100.93	13.13	105.91	13.88	111.13	12.49

Table 3  
*Children's Performance by Group on IQ Factor Scores and Measures of School Achievement*

	At-risk						Effect size (Cohen's <i>d</i> )		
	Dyslexic		Non-dyslexic		Control		RD vs. RND	RD vs. C	RND vs. C
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
Nonverbal ability (4 yr)									
Performance	-0.42 <sub>a</sub>	0.82	0.12 <sub>b</sub>	0.86	0.10 <sub>b</sub>	0.93	0.58	0.57	-0.01
Reasoning	-0.38 <sub>a</sub>	0.91	0.04 <sub>b</sub>	0.84	0.18 <sub>b</sub>	0.82	0.52	0.69	0.17
Verbal ability (4½ yr)	-0.45 <sub>a</sub>	0.93	-0.01 <sub>b</sub>	0.93	0.30 <sub>b</sub>	0.80	0.55	0.94	0.39
School achievement (end Grade 2)									
Reading	19.21 <sub>a</sub>	7.16	57.01 <sub>b</sub>	19.49	67.50 <sub>c</sub>	18.90	2.00	2.56	0.56
Arithmetic									
Addition	12.18 <sub>a</sub>	4.28	16.12 <sub>b</sub>	4.36	17.21 <sub>b</sub>	4.25	0.93	1.18	0.26
Subtraction	9.91 <sub>a</sub>	4.65	13.85 <sub>b</sub>	4.91	14.85 <sub>b</sub>	3.90	1.01	1.27	0.26

*Note.* Numbers and means in the same row that do not share subscripts differ at  $p < .05$  on Tukey's post-hoc test. Cohen's *d* is calculated using the *SDs* of the controls. RD = at-risk dyslexic, RND = at-risk non-dyslexic, C = control.

Table 4  
*Descriptive Statistics for all the Variables*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Nonverbal ability (4 yr)												
Performance												
1. Block design	-											
2. Patterns	.56	-										
3. Object assembly	.56	.43	-									
Reasoning												
4. Picture completion	.33	.23	.27	-								
5. Categories	.37	.36	.43	.40	-							
6. Analogies	.33	.23	.21	.22	.39	-						
Verbal ability (4½ yr)												
7. Language comprehension	.35	.31	.24	.24	.38	.38	-					
8. Expressive vocabulary	.26	.33	.22	.20	.39	.34	.67					
9. Expressive syntax	.19	.27	.16	.16	.31	.32	.56	.58	-			
10. Verbal short-term memory	.30	.30	.23	.25	.31	.27	.42	.48	.48	-		
School achievement (end Grade 2)												
11. Reading	.24	.25	.20	.13	.20	.16	.29	.26	.37	.27	-	
12. Arithmetic	.27	.26	.22	.15	.18	.19	.21	.07	.14	.21	.49	-
Mean	11.79	11.28	12.61	12.54	12.13	12.35	109.71	107.48	109.66	106.59	52.69	0.00
Standard deviation	3.06	3.20	2.77	3.28	3.09	2.84	11.89	14.35	13.00	13.73	24.75	0.95

*Note.*  $N = 212$ . Correlations  $> .13$  are significant at the .05-level and correlations  $> .22$  at the .001-level.

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Figure 1. Children's Performance on Nonverbal Ability Measures by Group

Figure 2. Children's Performance on Verbal Ability Measures by Group

Figure 3. Structural Equation Model of the Effects of IQ at Age 4 on Basic School Achievement at Age 8.



