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Response to early literacy instruction in the United States, Australia, and Scandinavia: A behavioral-genetic analysis

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Abstract

Genetic and environmental influences on early reading and spelling at the end of kindergarten and Grade 1 were compared across three twin samples tested in the United States, Australia, and Scandinavia. Proportions of variance due to genetic influences on kindergarten reading were estimated at .84 in Australia, .68 in the U.S., and .33 in Scandinavia. The effects of shared environment on kindergarten reading were estimated at .09 in Australia, .25 in the U.S., and .52 in Scandinavia. A similar pattern of genetic and environmental influences was obtained for kindergarten spelling. One year later when twins in all three samples had received formal literacy instruction for at least one full school year, heritability was similarly high across country, with estimated genetic influences varying between .79 and .83 for reading and between .62 and .79 for spelling. These findings indicate that the pattern of genetic and environmental influences on early reading and spelling development varies according to educational context, with genetic influence increasing as a function of increasing intensity of early instruction. Longitudinal analyses revealed genetic continuity for both reading and spelling between kindergarten and Grade 1 across country. However, a new genetic factor comes into play accounting for independent variance in reading at Grade 1 in the U.S. and Scandinavia, suggesting a change in genetic influences on reading. Implications for response-to-instruction are discussed.

Historically, and as late as 1800, more than 50% of the population in most western countries was illiterate. The opportunity to learn to read and write was a privilege, to a large extent determined by social-cultural conditions (Houston, 1999). Thus, illiteracy or poor literacy functioning was mainly caused by lack of education, and not by individual differences in response to teaching. Today, all western and many other countries provide compulsory education. Teaching is frequently regulated by a school curriculum with a strong emphasis on literacy in the first years in school. There is in addition a further goal of reducing the adverse impact of environmental factors such as low SES, as exemplified by many national declarations such as "No Child Left Behind" in the U.S., or "A School for All" in Sweden. Thus, from a historical perspective there are reasons to believe that individual capabilities, possibly of a genetic nature, increasingly contribute to phenotypic differences in reading and spelling skills, and that the importance of environmental differences wanes.

In this article, we continue to report on our International Longitudinal Twin Study (ILTS) of early language and literacy development (Byrne et al. 2002; Byrne et al. 2005; Byrne et al. 2006; Byrne et al. 2007; Samuelsson, et al. 2005; Samuelsson et al. 2007; Willcutt et al. 2007). The main purpose here was to compare genetic and environmental influences on early reading and spelling skills across three twin samples tested in the United States, Australia, and Scandinavia (i.e., Sweden and Norway) and across time of testing (i.e., kindergarten and Grade 1). Two questions are addressed: First, are there any differences in the pattern of genetic and environmental influences on early reading and spelling skills across country? Second, what are the changes in the pattern of genetic and environmental influences on reading and spelling from kindergarten to Grade 1? The general expectation is that the effects of environment on literacy skills should decrease and the genetic contribution increase as a function of intensity and consistency of instruction, across countries and time. This approach should also inform recent interest in response-to-intervention, or RTI, as a method to ascertain, define, and remediate reading difficulties (Compton, Fuchs, Fuchs, & Bryant, 2006; Fletcher, Coulter, Reschly, & Vaughn, 2004; Fuchs, Fuchs, & Compton, 2004; Fuchs & Young, 2006; Vellutino et al. 1996). So, for example, if our expectation that the intensity of instruction (intervention) affects the mix of genetic and environmental influences on literacy progress is realized, practitioners might bear in mind that genetic underendowment for reading and spelling will be particularly exposed with intense intervention and calibrate the pace and persistence of their activities accordingly.

The ILTS has previously documented substantial effects of genes and relatively minor effects of environmental influences on individual differences in literacy measures (word identification, reading comprehension and spelling) near the end of first grade in Australia and Colorado. Estimates of genetic effects are in order of .70 to .82 for word identification, .67 to .76 for reading comprehension and .39 to .76 for spelling across kindergarten to Grade 2 with shared environment generally limited to values in the order of .03 to .07 for reading, and somewhat higher for spelling (Byrne et al. 2007; in press). The genetic estimates are broadly similar to those obtained in other twin studies of early reading near the end of first grade. For instance, in the Twins Early Development Study (TEDS) being conducted in England and Wales, at 7 years the heritability of word identification, based on the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) was estimated at .70 (Kovas, Haworth, Dale, & Plomin, 2007). Using the UK National Curriculum (NC) criteria, which encompass a broad range of reading skills including word- and meaning-level strategies and with assessments by classroom teachers, the heritability was .68. Shared environment tended to be more influential in the TEDS study than the ILTS, with values of .15 based on the TOWRE and .07 based on the NC.

However, in a recent ILTS study of data collected near the end of kindergarten (Samuelsson et al. 2007), individual differences in reading and spelling skills were mainly accounted for by genetic factors in a sample of Australian twins, with estimates of .91 and .84, respectively. In contrast, in a sample of U.S. twins from the state of Colorado, only approximately half of the variance in reading and spelling was accounted for by genetic influences, with the other half attributed to shared and non-shared environment. Although these country differences in genetic and environmental influences on individual differences in reading and spelling were not statistically significant with the available sample sizes, we hypothesized that the trends might be explained by country differences in educational practice. Compulsory school starts at around age five in both Australia and Colorado, but in New South Wales, Australian children enter a school system regulated by a state-wide curriculum mandating that at least 35% of a full school week (9 am to 3 pm, five days a week) should be devoted to language and literacy instruction. In contrast, in Colorado children attend kindergarten school for only 3-4 hours each day, and there is no state-mandated curriculum for teaching reading and spelling. One plausible explanation for the different pattern of genetic and environmental influences on reading and spelling in Australia and U.S. is that a state-wide curriculum emphasizing intense literacy instruction reduces the environmental range in the population, and thus, the amount of variance in reading and spelling skills that can be accounted for by environmental factors. Another explanation is that the greater intensity of instruction in NSW engages genetically-influenced learning processes earlier than in the US, resulting in a higher genetic contribution to overall variability.

To further explore these hypotheses, the present study includes a sample of Scandinavian twins. In Scandinavia, compulsory school starts when the child is seven years old, that is, one to two years later compared to Australia and the U.S. Nevertheless, almost all children do attend kindergarten prior to compulsory attendance in Grade 1, but kindergarten curriculum in Sweden and Norway emphasizes social, emotional, and aesthetic development rather than early literacy acquisition. In this way, Scandinavia represents a population where environmental variation outside of school might have a substantial impact on individual differences in kindergarten reading and spelling skills because there is no formal reading instruction in kindergarten. Instead, literacy socialization is mainly given informally at home. However, at seven years of age, in Grade 1, teaching reading and spelling is the target activity in school, and literacy instruction is guided by a master plan common to all schools in Sweden and Norway. This change from informal literacy teaching taking place at the children's home to a country-wide curriculum emphasizing formal reading and spelling instruction should reduce environmental range and increase the intensity of engagement. From kindergarten to Grade 1, we hypothesize, therefore, that the heritability of literacy skills increases and the importance of shared environment decreases in Scandinavia.

To summarize, we hypothesize different contributions from genes and environment to kindergarten literacy skills across countries. We also hypothesize an increase in genetic effects on literacy from kindergarten to Grade 1, especially in Scandinavia where formal reading instruction is introduced one year later than in Australia and the U.S. These questions are addressed in the present study through univariate behavior-genetic analyses of data from identical and same-sex fraternal twins tested near the end of kindergarten and first grade. In addition to comparing the magnitudes of genetic and environmental influences between countries and grades in univariate analyses, with a multivariate approach we also address the question whether the same or different sources of genetic and environmental influences account for individual differences in literacy at kindergarten and Grade 1. Based on the differences in the curriculum for literacy instruction across countries summarized above, we hypothesize continuity in the pattern of genetic and environmental influences on reading and spelling from kindergarten to Grade 1 in Australia, but a possible change in genetic and environmental effects on literacy skills in Scandinavia, with the US representing an intermediate case.

Method

Participants

The kindergarten sample comprised a total of 812 same-sex twin pairs recruited from the Colorado Twin Registry in the U.S., the National Heath and Medical Research Council's Australian Twin Registry, and from the Medical Birth Registries in Norway and Sweden (see Table 1). New cohorts of twins are recruited each year, so at the time of writing the follow-up at the end of Grade 1 was not complete, with a total of 690 twin pairs available for analysis. Actual attrition because of families leaving the project is virtually zero. Only participants for whom the predominant language of their country (i.e., English, Swedish, or Norwegian) was the first language spoken at home were selected. There were no significant differences in parents' mean years of education across twin samples. Also, the means were around 14 years suggesting that level of education is representative for each country. Zygosity was determined by DNA analysis from cheek swab collection, or, in a minority of cases, by selected items from the questionnaire by Nichols and Bilbro (1966).

Literacy skills

Reading. Reading skills in kindergarten and Grade 1 were measured by both the word and nonword subtests from the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999), with both Forms A and B administered and averaged to increase reliability (test-retest reliability for children aged 6-9 years, .97 for word and .90 for nonword standard scores). In each Form, children read a list of words and a list of nonwords as quickly as possible in 45 sec. A composite measure of reading skill was created for phenotypic analyses, justified by high correlations, .83 and .86 on average, between word and nonword reading at both kindergarten and at the end of Grade 1. For the behavior genetic analyses, we modelled the four subtests of word and nonword reading as latent traits.

Spelling. At kindergarten, spelling was measured by a test developed by Byrne and Fielding-Barnsley (1993). The test was composed of ten simple words and four nonwords. In

Table 1

Mean Age (Standard Deviation) and Sample Size by Country, Zygosity and sex at the End of Kindergarten, and Grade 1

Characteristic	Australia	United States	Scandinavia
End of kindergarten			
Age (in months)	72.4 (4.2)	75.1 (3.7)	80.8 (3.6)
Total sample (pairs)	191	483	138
MZ pairs	113	224	65
DZ pairs	78	259	73
MZ girls	55	127	33
MZ boys	58	97	32
DZ girls	37	115	36
DZ boys	41	144	37
End of Grade 1			
Age (in months)	83.5 (4.3)	88.8 (3.9)	92.3 (3.5)
Total sample (pairs)	160	405	125
MZ pairs	98	185	59
DZ pairs	62	220	66
MZ girls	48	107	29
MZ boys	50	78	30
DZ girls	29	100	32
DZ boys	33	120	34

Note. Scandinavia = Norway and Sweden; MZ = monozygotic; DZ = Dizygotic

scoring the test, both phonological and orthographic accuracy contributing to the score with a possible range between 0-84 (for scoring details, see Byrne and Fielding-Barnsley). The correlation was .90 between words and nonwords and thus a composite measure of spelling skill was created (Cronbach α=.93; Hindson et al., 2005). As for reading, word and nonword spelling were modelled as a latent trait in the behavior genetic analyses.

The Wide Range Achievement Test (WRAT; Jastak & Wilkinson, 1984) spelling subtest was employed at the end of Grade 1. In this test, children spell words until they make ten consecutive errors and the score is the total number of words spelled correct out of the maximum of 45. Byrne et al (2007) report a lower-bound estimate of reliability based on the MZ correlation of .77. The correlation between the kindergarten spelling test and the WRAT was .68, reasonably substantial given the time gap of a year between assessments. The raw score for WRAT spelling was used in the behavior-genetic analyses.

All tests were translated into Swedish and Norwegian.

Procedure

Children were assessed individually by trained examiners in their homes and/or schools at the end of kindergarten and Grade 1. To foster fidelity of assessment between testers and sites, we have adopted the practice of videotaping samples of test sessions and having each tester inspect the tapes of other testers.

In this study, we only report on reading and spelling measures performed at each age. However, in single one-hour sessions at each of kindergarten and Grade 1, several other measures such as phonological awareness, RAN, and verbal abilities were included (for details, see Byrne et al. 2005; Byrne et al. 2006; Byrne et al. 2007).

Analysis

One-way analyses of variance (ANOVA) and Tukey HSD post hoc tests were performed to test differences between country samples for reading and spelling at kindergarten and Grade 1. The magnitude of the mean differences was calculated using Cohen's *d*. Genetic and environmental influences on reading and spelling skills across country and within country across time were analyzed using monozygotic (MZ) and dizygotic (DZ) twin correlations, and models were fitted from raw data using maximum likelihood estimation in Mx (Neal, Boker, Xie, & Maes, 2002). Mx was also used to fit Cholesky decomposition models addressing the question of whether the same or different genetic and environmental factors influences reading and spelling skills in kindergarten and Grade 1.

Results

Reading and spelling skills across country

Means and standard deviations for reading and spelling at kindergarten and Grade 1 across country and effect size estimations for mean differences are presented in Table 2. There were significant differences between all three countries for reading at both kindergarten and Grade 1. In Scandinavia, there are some children performing at a level close to zero on reading at kindergarten, but the rate of improvement in reading from kindergarten to Grade 1 is comparable with the improvements observed for Australian and U.S. twins.

A similar pattern of differences between twin samples was obtained for kindergarten spelling. However, spelling results at the end of Grade 1 show a different pattern. The mean spelling performance for the Scandinavian twin sample was significantly higher than in Australia and U.S. This difference is most likely biased due to test translation from English to Scandinavian versions of the WRAT spelling test. In addition, many words in Swedish and Norwegian can be spelled using simple rules for phoneme-grapheme correspondences. The main point here is that growth in spelling skills in Scandinavia is comparable with that obtained in Australia and U.S. There was no significant difference in spelling between the Australian and U.S. samples at the end of first grade.

Table 2

Means and Standard Deviations for Reading and Spelling Skills (raw scores) at the End of Kindergarten and Grade 1 Across Sample and Effect Size Estimation for Differences Between Twin Samples

	Australia		United States		Scandinavia				
Variable	M	SD	M	SD	M	SD	d^1	d^2	d^3
End of kindergarten									
Reading	14.2	10.7	8.6	9.1	5.3	9.2	.57*	.89*	.36*
Spelling	63.4	14.9	50.9	20.1	41.2	30.9	.71*	.91*	.37*
End of Grade 1									
Reading	31.4	14.1	27.7	13.3	21.1	13.1	.27*	.76*	.50*
Spelling	13.7	5.1	12.6	5.2	16.4	7.3	.21	-.43*	-.60*

Note. d^1 = Effect size for the difference between Australia and U.S.; d^2 = Effect size for the difference between Australia and Scandinavia; d^3 = Effect size for the difference between U.S. and Scandinavia

*$p<.001$

Behavior-genetic analyses

Standardized raw data adjusted for age and gender effects within each twin sample were used as input for all behavior-genetic analyses. To estimate the relative influence on individual differences from additive genetic effects (a^2), shared-environment effects (c^2), and nonshared-environment effects (e^2), the data for reading and spelling skills were subjected to structural equation modelling by use of the Mx statistical modelling package (Neale, Boker, Xie, & Maes, 2002). In this section, we start by presenting correlations between MZ and DZ twins. These correlations provide preliminary estimates of genetic, shared environment, and nonshared environment influences on reading and spelling. Additive genetic effects (a^2) can be approximately estimated by doubling the difference between the MZ and DZ twin correlations because in terms of genetics, DZ twins are half as similar, on average, as compared to genetically identical MZ twins (see Plomin, DeFries, McClearn, & McGuffin, 2008, for an introduction to twin methodology). Non-shared environment (e^2) is estimated as 1 – the MZ correlation, and shared environment is estimated from the difference between the MZ correlation and a^2. Next, we present univariate estimates of reading and spelling at end of kindergarten and grade 1 using the structural equation modelling package Mx. Finally, developmental Cholesky analyses are presented which assess genetic and environmental contributions to the covariance between kindergarten and first grade reading and spelling. These analyses address to what extent the same or different genetic and environmental factors influence reading and spelling at kindergarten and Grade 1.

Twin correlations for reading and spelling across samples. MZ and DZ twin correlations for reading and spelling are presented separately in Table 3 for the Australian, U.S., and Scandinavian samples at kindergarten and Grade 1. Although the MZ correlations were always higher than the DZ correlations for both reading and spelling in all samples and across time, suggesting genetic influences, the size of the differences between MZ and DZ correlations vary considerably across country and across time of testing. We therefore turn to model results to explore these differences more systematically.

Univariate Mx analyses. The results of Mx analyses of the MZ and DZ twins' raw data for estimates of genetic (a^2), shared environment (c^2), and non-shared environment (e^2) on latent traits for reading and spelling at kindergarten and Grade 1 are presented separately for each country in Table 4. The pattern of genetic and environmental influences on reading suggested by the differences in MZ and DZ correlations displayed in Table 3 are confirmed by the pattern of Mx estimates presented in Table 4. There are significant but variable genetic influences on reading in all three twin samples at the end of kindergarten. As can be seen,

Table 3

Intraclass Twin Correlations for Reading and Spelling at Kindergarten and Grade 1 Across Twin Samples

	Australia		United States		Scandinavia	
Variable	MZr	DZr	MZr	DZr	MZr	DZr
End of kindergarten						
Reading	.90	.44	.89	.55	.84	.68
Spelling	.79	.45	.77	.58	.83	.58
End of Grade 1						
Reading	.79	.27	.86	.45	.86	.49
Spelling	.79	.24	.76	.44	.79	.34

estimated genetic influences on kindergarten reading are .84 in Australia .68 in the U.S., and .33 in Scandinavia. These differences in genetic influences on reading across country correspond with the assumption that genetic influences should increase as a function of intensity of early formal reading instruction. It should be noted that the difference in estimated genetic influences on kindergarten reading between Australia and Scandinavia is statistically significant (i.e., confidence intervals do not overlap), but that otherwise the intervals do overlap. The effects of shared environment on kindergarten reading also vary substantially across twin samples. While the effects of shared environment are significant and as high as .52 in the Scandinavian sample, no significant shared environmental influences were obtained on reading in the Australian sample. Again, the U.S. sample represents an intermediate case where the effect of shared environment was significant at .25. However, as with genetic estimates, the confidence intervals for shared environment estimates overlap. It is hoped that with larger samples in this progressive study in future years that these intervals will narrow, alleviating the uncertainties currently surrounding the interpretation of the point estimates.

Table 4

MX Model Fitting Estimates (and Confidence Intervals) for Latent Traits of Reading and Spelling Within Each Twin Sample at (a) Kindergarten and (b) Grade 1

Variables	a^2	c^2	e^2
(a)			
Reading			
Australian sample	.84 (.61, .94)	.09 (.00, .31)	.08 (.05, .11)
U.S. sample	.68 (.54, .84)	.25 (.09, .39)	.07 (.05, .09)
Scandinavian sample	.33 (.11, .60)	.52 (.26, .71)	.15 (.10, .23)
Spelling			
Australian twins	.74 (.44, .95)	.17 (.00, .45)	.10 (.04, .17)
U.S. twins	.44 (.27, .63)	.41 (.23, .56)	.15 (.10, .21)
Scandinavian twins	.46 (.17, .83)	.42 (.06, .68)	.12 (.06, .21)
(b)			
Reading			
Australian sample	.80 (.52, .87)	.02 (.00, .28)	.18 (.13, .26)
U.S. sample	.83 (.65, .92)	.07 (.00, .24)	.11 (.08, .14)
Scandinavian sample	.79 (.46, .89)	.07 (.00, .38)	.14 (.09, .22)
Spelling			
Australian twins	.79 (.44, .95)	.00 (.00, .19)	.20 (.15, .28)
U.S. twins	.62 (.42, .78)	.13 (.00, .32)	.24 (.20, .31)
Scandinavian twins	.69 (.44, .82)	.09 (.00, .31)	.22 (.15, .33)

Note. Estimates with 95% confidence intervals including .00 are not significantly greater than 0.

The pattern of genetic and environmental influences on spelling across twin samples is similar to that obtained for reading. Genetic influences account for most of the variance (74%) in spelling in Australia, and the effects of shared environment did not reach significance. For the U.S. and Scandinavian twin samples, the influences from genes and shared environment on spelling were both significant, and estimated at approximately .45 and .40, respectively. However, the effects of genes increased and the effects of shared environment decreased substantially in both U.S. and Scandinavia in Grade 1, reaching estimates at levels similar to those obtained in Australia at kindergarten. This change in the pattern of genetic and environmental influences on reading and spelling from kindergarten to Grade 1 among U.S. twins and especially in the Scandinavian sample suggests that the effects of shared environment on individual differences in literacy skills decrease to negligible levels after only one or two years of formal schooling.

Developmental Cholesky analyses. In Table 5, we present a Cholesky decomposition for reading in Australia, the U.S., and Scandinavia. The Cholesky decomposition model is a powerful tool in behaviour-genetic analyses of twin data (Neale et al. 2002). Similar to stepwise hierarchical regression in phenotypic analyses, it allows us to assess the relations among variables after controlling for relations with variables entered earlier in the model. However, with data from MZ and DZ twins reared together, we can also separate the genetic, shared environment, and non-shared environment contributions to those relations. Thus, these longitudinal analyses address whether genetic factors that account for individual differences in reading at the end of kindergarten also influence reading one year later at the end of Grade 1. Similarly, we can ask whether the environmental factors that affect reading at kindergarten are the same that influence reading at Grade 1. We can also ask whether new genetic and environmental influences come into play in accounting for reading in Grade 1. In all three twin samples, there is a significant genetic factor common to reading at both kindergarten and Grade 1. Thus, genetic factors affecting kindergarten reading also account significantly for individual differences in reading one year later at the end of Grade 1. The second independent A2 path to Grade 1 reading varies in magnitude and statistical significance across the three samples. In

Australia, it is estimated at .37, accounting for 14% of the phenotypic variance, but it is not statistically significant. In contrast, for the U.S. sample the A2 path of .55 indicates significant unique genetic effects that account for 30% of the variance in reading at Grade 1. The independent path to Grade 1 reading in the Scandinavian sample was even higher (.63) indicating that 40% of the phenotypic variance in Grade 1 reading is accounted for by a second unique genetic factor. However, this path did not reach significance, most likely due to the small sample size in Scandinavia. In future reports, when the sample sizes are larger, we hope to resolve the uncertainty that now surrounds the A2 paths for the smaller Australian and Scandinavian samples, where current values may represent chance fluctuations.

In Australia, there was no significant shared environment factor for kindergarten or for Grade 1 reading. In contrast, as shown previously, kindergarten reading was affected by a significant shared environment factor in both the U.S. and the Scandinavian twin samples. However, this significant kindergarten shared environment factor did not contribute significantly to reading at Grade 1, nor was there a second independent shared environment factor accounting for significant variance in reading in Grade 1. The developmental Cholesky analyses suggest that, unlike genetic effects, which contribute significantly to continuity in all three samples, as well as change in the U.S. and Scandinavia, shared environment effects only contribute significantly to individual differences in reading before children are exposed to formal reading instruction.

Finally, in all three samples, the non-shared environment paths show significant continuity from kindergarten to Grade 1, and also significant new non-shared environment influences on grade 1 reading. However, some of the non-shared environment influences are likely due to measurement error.

Table 5

Standardized Path Coefficients (95% Confidence Intervals in Parentheses) From a Cholesky Decomposition Model of Genetic (A), Shared Environment (C), and Non-shared environment (E) Influences on Kindergarten and Grade 1 Reading Across Twin Samples

	Variable	
Factor	Kindergarten reading	Grade 1 reading
Australia		
A1	.91 (.78, .97)	.81 (.65, .90)
A2		.37 (.00, .53)
C1	.29 (.00, .55)	.00 (.00, .49)
C2		.13 (.00, .45)
E1	.28 (.23, .33)	.20 (.12, .30)
E2		.38 (.32, .45)
U.S.		
A1	.82 (.73, .92)	.72 (.60, .82)
A2		.55 (.45, .65)
C1	.50 (.30, .63)	.13 (.00, .35)
C2		.22 (.00, .41)
E1	.26 (.23, .30)	.14 (.09, .20)
E2		.29 (.25, .34)
Scandinavia		
A1	.57 (.32, .77)	.63 (.30, .90)
A2		.63 (.00, .76)
C1	.72 (.51, .84)	.27 (.00, .53)
C2		.00 (.00, .47)
E1	.39 (.32, .48)	.18 (.09, .28)
E2		.33 (.26, .41)

Note. 95% confidence intervals are in parentheses. 00 are not significantly greater than 0.

Results from the developmental Cholesky models for spelling are presented in Table 6. The pattern of results for spelling is for most aspects replicating the results obtained for reading. First, there is one significant genetic factor common to spelling at both kindergarten and Grade 1 across all three twin samples. Second, one shared environment factor contributes to variance in kindergarten spelling in the U.S. and Scandinavia, but this factor did not significantly account for individual differences in spelling at the end of Grade 1. Also, the effect of shared environment on spelling was negligible in the Australian sample at both kindergarten and Grade 1. Third, there was no significant second independent effect of shared environment on spelling at Grade 1 across all three twin samples. One finding for spelling was not fully replicated compared to the analyses on reading. While a second genetic factor accounted for significant independent variance in reading at Grade 1 in the U.S. twin sample, there was no significant second genetic factor affecting spelling at Grade 1. However the nonsignificant A2 path coefficients of .43 (Australia), .45 (U.S.), and .46 (Scandinavia) suggest the presence of a second genetic factor accounting for about 20% of the phenotypic variance in grade 1 spelling that may become significant with an increase in sample size.

The non-shared environmental paths for spelling show significant continuity from kindergarten to Grade 1 in the Australian and U.S. samples, and significant new non-shared environmental influences on Grade 1 in all three samples. Again, some of the non-shared environment influences are likely due to measurement error.

Following the procedures described in Keenan, Betjeman, Wadsworth, DeFries, and Olson (2006), the results of the Cholesky models were used to estimate the genetic (r_A), shared environment (r_C), and non-shared environment (r_E) correlations between the two test occasions for reading and spelling in the three samples. These correlations reflect the degree to which individual differences at the end of kindergarten and first grade are due to the same sources of influence, regardless of the magnitude of those influences at each time point. The genetic

Table 6

Standardized Path Coefficients (95% Confidence Intervals in Parentheses) From a Cholesky Decomposition Model of Genetic (A), Shared Environment (C), and Non-shared environment (E) Influences on Kindergarten and Grade 1 Spelling Across Twin Samples

	Variable	
Factor	Kindergarten spelling	Grade 1 spelling
Australia		
A1	.86 (.67, .98)	.78 (.59, .91)
A2		.43 (.00, .60)
C1	.41 (.00, .67)	.05 (.00, .40)
C2		.00 (.00, .37)
E1	.31 (.20, .41)	.15 (.02, .30)
E2		.43 (.35, .51)
U.S.		
A1	.67 (.52, .80)	.65 (.46, .83)
A2		.45 (.00, .61)
C1	.64 (.48, .75)	.25 (.00, .44)
C2		.26 (.00, .45)
E1	.39 (.32, .46)	.22 (.13, .31)
E2		.44 (.39, .50)
Scandinavia		
A1	.68 (.41, .91)	.69 (.42, .90)
A2		.46 (.00, .62)
C1	.65 (.25, .82)	.30 (.00, .55)
C2		.00 (.00, .37)
E1	.35 (.25, .46)	.13 (.00, .29)
E2		.45 (.37, .55)

Note. 95% confidence intervals are in parentheses. 00 are not significantly greater than 0.

correlations presented in the left half of Table 7 are quite high across all three samples for both reading and spelling, though they are less than perfect (1.0), and we previously noted that the genetic Cholesky analysis of reading in the larger US sample showed that there was a significant additional genetic influence on individual differences at the end of first grade that was independent from genetic influences expressed at the end of kindergarten.

Table 7

Genetic (r_A), Shared environment (r_C), and Non-shared environment (r_E) Correlations (left half of the table) and Phenotypically Standardized Correlations (r_{Ap}, r_{Cp}, and r_{Ep}) as well as Total Phenotypic (r_p) Correlations (right half of the table) Between Kindergarten and Grade 1 for Reading and Spelling in the Three Samples

	Genetic and Environmental Correlations			Phenotypically Standardized Correlations			
Variable	r_A	r_C	r_E	r_{Ap}	r_{Cp}	r_{Ep}	r_p
Reading							
Australia	.91	.01	.48	.75	.00	.06	.81
U.S.	.79	.51	.44	.59	.07	.04	.70
Scandinavia	.71	1.0	.48	.36	.19	.07	.62
Spelling							
Australia	.87	1.0	.33	.67	.00	.05	.72
U.S.	.82	.62	.44	.43	.16	.08	.67
Scandinavia	.83	1.0	.28	.47	.19	.05	.71

The importance of the genetic and environmental correlations in accounting for the phenotypic correlations between measurement occasions (i.e., the Phenotypically Standardized Correlations) is shown in the right half of Table 7. Adding the phenotypically standardized correlations for genetic (r_{Ap}), shared environment (r_{Cp}), and non-shared environment (r_{Ep}) yields the total phenotypic correlations (r_p) between measurement occasions that are shown in the far left column of Table 7. It is apparent that most of the phenotypic correlation between measurement occasions for reading and spelling in each sample is due to shared genetic influences. Although some of the shared environment correlations (r_C) are quite high, none are significantly greater than 0 as estimated from the Cholesky models, and their phenotypically standardized shared environment correlations (r_{Cp}) are relatively low. Finally, the moderate non-shared environment correlations are mostly significant as estimated from the Cholesky models (spelling in Scandinavia the only exception), but they account for only small proportions of the total phenotypic correlations.

Discussion

Previous reports from two ongoing twin studies have shown that genetic influence on individual differences in reading is substantial (~70% heritability) among 7 year old twins at the end of first grade (Byrne et al. 2005; 2006; Harlaar, Spinath, Dale & Plomin, 2005). The study by Samuelsson et al (2007) was the first to compare genetic and environmental contributions to literacy skills as a function of intensity of reading instruction in kindergarten. By comparing an Australian twin sample entering a school system with strong emphasis on literacy instruction with U.S. twins receiving approximately half the time of instruction, estimated heritability was 1.5 and 2.5 times higher in Australia on reading and spelling, respectively. Significant shared environment effects on kindergarten reading and spelling were only obtained in the U.S. sample. One way to interpret this difference between Australia and the U.S. is that genes that affect early reading and spelling skills cannot show their contributions fully until children participate in intense literacy instruction.

The present study offers additional support for different patterns of genetic and environmental influences as a function of intensity of early literacy instruction. In a same-age twin sample attending kindergarten in Scandinavia, where children rarely receive any literacy instruction in kindergarten, genetic effects were estimated at .33 for reading and .46 for spelling. Most of the variance in reading (52%) and a substantial proportion of the variance in spelling (42%) were accounted for by shared environment in Scandinavia. However, one year later, when twins in all three samples have received intense literacy instruction for at least one full school year, heritability was similarly high across country and estimated genetic influences varied between .79 and .83 for reading and between .62 and .79 for spelling.

Multivariate analyses showed that genetic influences on reading in kindergarten overlap with genetic influences on reading observed at Grade 1. This finding was replicated across country. However, a new genetic factor comes into play accounting for independent variance in reading at Grade 1 in the U.S. and Scandinavia, implicating a change in genetic influences on reading. This second unique genetic factor was significant in the U.S. sample and accounted for 30% additional variance in Grade 1 reading. Although not significant, a second independent genetic factor accounting for 40% of the variance in reading at Grade 1 was found in the Scandinavian sample. Although the confidence intervals for the A2 path coefficients show that the country differences are not significant, their order (Australia = .37, U.S. = .55, Scandinavia = .63) suggests that a new genetic factor was increasingly affecting individual differences in reading at Grade 1 as children in the U.S. and the Scandinavian samples were more engaged in literacy instruction.

Interestingly, there was little or no unique shared environment effect on reading at Grade 1 across country, the largest C2 path being .22 for the U.S. sample. Also, there were no significant shared environment influences common to those present at kindergarten, the largest C1 to C2 path being .27 in Scandinavia. One possible implication of this finding might be that there is no substantial school and/or teacher effect on individual differences in reading skills (cf. Byrne, Olson, Hulslander, Samuelsson, & Harlaar, 2007; Olson, 2006; Olson et al. 2006).

To sum up, the longitudinal analyses revealed genetic continuity for both reading and spelling between kindergarten and Grade 1 across country. However, change in genetic contributions to reading was evident in both the U.S. and Scandinavian samples. Shared environment effects were only affecting reading and spelling in U.S. and Scandinavia, and only at the beginning of literacy development at the end of kindergarten.

Implications for RTI

Our International Longitudinal Twin Study demonstrates the importance of a genetically sensitive design for understanding the etiology of individual differences and the role of general education in literacy instruction. By comparing three twin samples derived from three countries with different curriculum for early literacy instruction, we were able to study the pattern of genetic and environmental influences on both single-age and age-to-age changes in reading and spelling as a function of intensity of classroom instruction. It is interesting to speculate on the meaning of these findings for response-to-instruction (RTI). One idea underlying RTI is to observe age-to-age changes in reading and spelling achievement to improve identification of reading disability and the selection of at-risk readers for intervention (Compton, Fuchs, Fuchs, & Bryant, 2006). If successful, individual differences in reading and spelling skills accounted for by lack of or limited reading instruction should be successively reduced, implying that unresponsiveness to generally effective literacy instruction should be increasingly accounted for by individual capabilities. Our findings seem to support this general assumption. In terms of behavior-genetic analyses, genes seem to increasingly account for individual differences in response to classroom instruction in literacy, and shared environment declines in importance.

Perhaps counter intuitively, effective classroom instruction generally increases heritability of reading and spelling. More generally, if we succeed with school policies such as “No Child Left Behind” in the U.S.A. or “A School for All” in Sweden, then genes will increasingly account for individual differences in literacy skills.

Limitations

Even though there was overlap among most of the confidence intervals, we consider it noteworthy that the point estimates for heritability and for shared environment across the Australian, U.S., and Scandinavian samples align with the intensity of kindergarten literacy instruction--the more intense the instruction, the higher the heritability and the lower the common environment influences. When larger samples permit, we will re-examine the confidence intervals, which should narrow, and we will converge on the current analyses with model-fitting, determining if by equating the parameters for each sample we lose fit to the data. For the moment we advance a plausibility argument for our conclusions about the relation between the etiological profiles and instructional regimens, with the caution that must accompany such an argument. In addition, a new sample of Norwegian twins will be tested in 2007; the same year as a new curriculum was introduced in Norway with the main purpose being to introduce formal literacy instruction one year earlier (i.e., at six years of age). This major change in literacy education will allow us to study genetic and environmental effects on reading and spelling as a function of intensity of literacy instruction in a more straightforward way.

We have reported on differences in kindergarten educational practices and opportunities in Australia, the US, and Scandinavia, but we do not have direct classroom observations to reinforce our claims. Our twins were distributed over almost as many schools as there are pairs, so the expense to gathering comprehensive information of this type is beyond the project’s resources. To the extent that actual practices in the classrooms that the twins attend may not reflect what we believe are the norms for each country, the attribution of the differing patterns of results to educational practices will be the less secure.

Despite these caveats, the dual findings of differences in estimated genetic and environmental influences on reading and spelling across country at kindergarten and a change in heritability suggesting high and similar estimates of genetic effects across country at Grade 1 indicate that individual differences in response to early literacy instruction are increasingly accounted for by genetic factors as the intensity and consistency of instruction increases. In general, our results support the basic RTI approach that recognizes the need for more intense instruction for poor readers that are not otherwise instructional failures, which our results say are most poor readers at the end of first grade for the samples in our three countries.

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