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Genetic and environmental influences on prereading skills and early reading and spelling development in the United States, Australia, and Scandinavia

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Abstract. Genetic and environmental influences on prereading skills in preschool and on early reading and spelling development at the end of kindergarten were compared among samples of identical and fraternal twins from the U.S. (Colorado), Australia, and Scandinavia. Mean comparisons revealed significantly lower preschool print knowledge in Scandinavia, consistent with the relatively lower amount of shared book reading and letter-based activities with parents, and lack of emphasis on print knowledge in Scandinavian preschools. The patterns of correlations between all preschool environment measures and prereading skills within the samples were remarkably similar, as were the patterns of genetic, shared environment, and non-shared environment estimates: in all samples, genetic influence was substantial and shared environment influence was relatively weak for phonological awareness, rapid naming, and verbal memory; genetic influence was weak, and shared environment influence was relatively strong for vocabulary and print knowledge. In contrast, for reading and spelling assessed at the end of kindergarten in the Australian and U.S. samples, there was some preliminary evidence for country differences in the magnitude of genetic and environmental influences. We argue that the apparently higher genetic and lower shared environment influence in the Australian sample was related to a greater emphasis on formal reading instruction, resulting in more advanced reading and spelling skills at the end of kindergarten, and thus there was greater opportunity to observe genetic influences on response to systematic reading instruction among the Australian twins.

Our International Longitudinal Twin Study (ILTS) of early reading development involves U.S., Australian, and Scandinavian samples of twins born between 1994 and 2000 in Colorado, the Sydney area, and in Sweden and Norway. The twins are assessed in preschool for prereading skills and their prereading environment. Their subsequent reading and spelling development is being assessed at the end of kindergarten and first and second grades (Byrne et al., 2002, 2005, 2006, this volume; Samuelsson et al., 2005; Willcutt et al., this volume). The overall aim of this cross-national and cross-language twin study is to identify genetic and environmental factors that influence young children's growth in language and literacy. The inclusion of twins from different countries tested on parallel measures provides a unique opportunity to assess the effects of cultural and language differences on genetic and environmental influences in early literacy acquisition.

Although genetic influence on different aspects of language and cognitive skills that are important for subsequent reading and spelling development is well established, the magnitude of genetic estimates has varied across studies (see Grigorenko, 2001; Stromswold, 2001 for reviews). For example, Byrne et al. (2005) and Samuelsson et al. (2005) estimated the heritability for individual differences in a latent trait for phonological awareness in their combined U.S., Australian, and Scandinavian samples at $h^2 = .61$, while Kovas et al. (2005) reported a heritability at $h^2 = .38$ for a single measure of phonological awareness in their sample of English preschool twins. Differences in estimated heritability for individual differences on verbal memory showed the same pattern, with stronger genetic influence obtained in the ILTS ($h^2 = .57$) compared to the estimate from Kovas et al. ($h^2 = .36$). In the other direction, the ILTS found much less genetic influence on a latent trait for vocabulary ($h^2 = .32$) compared to a substantial genetic influence of $h^2 = .52$ reported by Kovas et al. There are also considerable variations in the results estimating the impact of environmental influences on prereading skills. Previous ILTS analyses of the combined U.S., Australian, and Scandinavian twin samples indicated that although genetic influence was dominant, there was also significant influence from shared environment on latent-traits for phonological awareness, verbal memory, and vocabulary (Samuelsson et al., 2005). In contrast, Kovas et al. reported that there were no significant influences from shared environment on these abilities.

Without exception, previous research addressing the etiology of prereading skills has investigated individual differences for a particular trait in a particular population (e.g., Kovas et al., 2005) or averaged across populations (e.g., Byrne et al., 2005; Samuelsson et al., 2005), and thus, there are several potential reasons for the differences that have been found between previous genetic and environmental estimates, beyond those related to the small sample sizes and possible sampling error in many of the studies reviewed by Stromswold (2001). First, there is the challenge of testing 4–5 year-old children and obtaining reliable estimates of their prereading skills. The ILTS has employed multiple measures of most skills and latent-trait behavior genetic analyses that have resulted in relatively low estimates of non-shared environment influences, compared to the relatively high non-shared environment influences reported by Kovas et al. (2005). If the high non-shared environment influence for the Kovas et al. single measure of phonological awareness was largely due to measurement error, the true genetic and environmental influences on phonological awareness in their sample might be higher. Second, in addition to the problem of differences in measure reliabilities across studies, the specific aspects of phonological awareness and other skills that are assessed in different measures could vary between studies. Third, differences in sample characteristics might result in differences between studies for estimates of genetic and environmental influence. These differences could include the environmental range within the samples and their average levels of preliteracy and early literacy skills. It is therefore difficult to know why previous studies with different populations and measures have come to different conclusions about the relative impact of genetic, shared environmental, and non-shared environmental influences on prereading skills.

In the ILTS, we are attempting to clarify the basis for similarities and differences across populations in estimates of genetic and environmental influences on early literacy development in the following ways. First, we employ the same measures across our three samples, differing only in their translation from English to Norwegian or Swedish for the Scandinavian cohort. Second, we use multiple measures of most prereading skills to maximize reliability and allow for latent trait modelling that minimizes the contribution of measurement error to our estimates of non-shared environment influences. Third, we assess the means and variances for different early literacy related activities in the home, including parent reading activities and education. Variance differences between samples on the environmental measures would indicate that the samples differ in their environmental range, and greater environmental range in a sample could lead to higher estimates of shared environment and lower estimates of genetic influence (Plomin, DeFries, McClearn, & McGuffin, 2001).

At preschool age, one main difference in family and preschool environment is apparent between Scandinavia on the one hand and Australia and the U.S. on the other hand. In Scandinavia (both Norway and Sweden), compulsory education starts when the child is 7 years old (Lundberg, 1999), and there is an established tradition that children should not be subjected to any formal or informal reading instruction until school starts. This attitude towards early literacy acquisition is cemented by a master plan common to all preschools in Sweden and Norway. The main theme in the preschool curriculum is to emphasize social, emotional, and aesthetic development rather than intellectual preparation for school work. This opinion is also well integrated among most parents in Scandinavia. Thus, we hypothesized that a majority of Scandinavian twins would exhibit limited knowledge about print and only a few children would be able to read simple words before 7 years of age. The situation in English-speaking countries is quite the opposite. These countries generally favor early informal and sometimes formal reading instruction in the home and preschool (Mann & Wimmer, 2002), though there is considerable variation across families and preschools. This difference in family and preschool environment between Scandinavia and English-speaking countries should have an average impact on prereading skills, particularly those related to early print knowledge.

We did not have a clear hypothesis about how mean differences in prereading skills would be related to genetic and environmental influences on those skills, as long as there were no differences in floor or ceiling effects between samples for our measures, and the variances were not significantly different between samples. However, we did hypothesize that sample differences in the emphasis on subsequent formal literacy instruction in the schools could lead to differences in genetic and environmental estimates of early reading development at the end of kindergarten. At kindergarten age, an interesting difference occurs between the Australian and the U.S. twin samples. In New South Wales, Australia, twins enter a school system at kindergarten in which a state-wide curriculum guides instruction, using amongst other things a series of "indicators" and "outcomes" (some examples from kindergarten; *child recognizes and supplies rhymes; recognizes spoken words with same sound; recognizes some letters and sounds beyond those in own name*). In addition, the children attend full school days (roughly 9 am to 3 pm), 5 days a week, and a minimum 35% of the school week is recommended for language and literacy instruction. (L. Graham, personal communication, September, 2005). Both the curriculum guiding teaching in reading and spelling and the amount of time invested to teach literacy should have a substantial impact on average reading and spelling skills at the end of kindergarten in Australia. The kindergarten school system in Colorado is characterized by much more diversity with a range of alternative educational settings for literacy instruction, and there is no state standard for teaching reading and spelling in kindergarten. In addition, Colorado children typically attend kindergarten for only 3–4 hours each day. Given these differences between school systems in Australia and the U.S., we hypothesized that by the end of kindergarten, Australian twins would develop reading and spelling skills at a higher level compared to U.S. twins.

We expected that Scandinavian twins would be largely illiterate at the end of their kindergarten year, and this was confirmed. Approximately 50% of the Scandinavian twins were unable to read any words at the end of kindergarten prior to formal reading instruction at age seven in first grade, and we do not yet have a sufficient Scandinavian sample of twins that have been assessed at the end of first grade. Therefore, the present analyses of individual differences in reading skills are limited to the Australian and U.S. samples at the end of kindergarten.

We hypothesized that genetic influence might be higher and shared environment influence might be lower in the Australian sample compared to the U.S. sample, for two reasons. First, we thought that the apparently more consistent literacy curriculum in New South Wales kindergartens would reduce the environmental range for reading development, leading to a lower estimate of shared environment influence and a higher estimate of genetic influence. We also hypothesized that we would see evidence for a more restricted environmental range in the Australian sample based on lower variance in their reading skills, compared to the U.S. sample. The second reason that we expected greater genetic influence in the Australian sample was that with more formal literacy instruction, there would be more opportunity to observe reliable individual differences in response to formal reading instruction. We will expand on this idea in the discussion.

The preschool measures employed in the ILTS were selected in light of previous research on the important predictors of later reading development and from studies of preschool children at familial risk for reading deficiencies (Byrne, Fielding-Barnsley, Ashley, & Larsen, 1997; Byrne, Shankweiler, & Hine, in press; Hindson et al., 2005). In the risk studies, variables that clearly discriminated between preschool children bearing a family risk and those not included vocabulary, print familiarity and letter knowledge, aspects of phonological awareness, measures of verbal short-term memory, verbal fluency, and nonverbal intelligence. Scarborough (1998) identified six prereading skills with average correlations with subsequent reading development ranging between .32 and .49. Preschool print knowledge showed consistently high correlations with early reading acquisition, with an average correlation of .49. Phonological awareness was also consistently found to be related to subsequent early reading development with an average correlation of .46. Rapid automatized naming (RAN) was a third factor accounting for substantial independent variance in predicting early literacy development, with an average correlation of .38. In addition, verbal memory, vocabulary, and grammar and morphological skills accounted for significant variation in early reading and spelling development. Average correlations between these prereading skills and later skill in reading were estimated at approximately .30. Therefore, in the present study, a total of 19 measures of prereading skills were used to create composite scores of phonological awareness, rapid naming, verbal memory, vocabulary, grammar/morphology, and print knowledge.

Previous longitudinal studies have also found reliable correlations between home literacy activities and the development of children's language and beginning reading skills. Parental involvement in literacy activities such as shared book reading, number of books in the home, and library visits seem to be most strongly related to children's verbal abilities, and to preschool print knowledge (Sénéchal & LeFevre, 2002; Storch & Whitehurst, 2002). There is much less support for an association between literacy activities in the home and growth in preschool phonological awareness (see Whitehurst & Lonigan, 1998 for a review). In the present study, a total of 19 questions derived from two questionnaires were used to create composite scores for shared book reading, letter-based activities, print motivation, and parent reading behavior. In addition, parent level of education was used as a fifth index of home environment.

For our assessments of reading and spelling skills at the end of kindergarten in the Australian and U.S. samples, we focused on results from three measures of early literacy. These include standardized measures of phonological decoding (nonword reading) and word-reading efficiency, and an experimental measure of spelling production accuracy. The reading measures were also modelled as latent traits in the behavior-genetic analyses.

In summary, our main questions and hypotheses were the following. First, we asked how the different samples compared on prereading skills and potentially related environmental measures. We predicted that Scandinavian cultural constraints on early print exposure should be reflected in that sample's environmental measures and print knowledge, but regardless of any mean sample differences, the within-sample variances and correlations among the measures would be similar across the samples. Second, within each sample, we compared the similarities of identical and fraternal twins to estimate genetic and environmental influences on individual differences in prereading skills. We hypothesized that if there were similar within-sample variances and correlations among the preschool environment and ability measures, the patterns of genetic and environmental influences would also be similar across the samples. Third, we examined the means and variances for reading and spelling skills of the Australian and U.S. samples at the end of kindergarten. We hypothesized that the Australian mean would be higher due to greater emphasis on kindergarten reading instruction in that sample, but its variance would be lower due to a more uniform curriculum. Fourth, we compared the within-sample estimates of genetic and environmental influences on reading and spelling skills in the Australian and U.S. samples at the end of kindergarten. We predicted that if the Australian means were higher and variances were lower, this would be linked to higher genetic and lower shared environment influences in the Australian sample.

Method

Participants

The preschool sample comprised 809 same-sex twin pairs recruited from the Colorado Twin Registry in the U.S., the National Health and Medical Research Council's Australian Twin Registry, and from the Medical Birth Registries in Norway and Sweden (see Table 1). Only participants for whom the predominant language of their country (English, Swedish, or Norwegian) was the first language spoken at home were selected. Parents of the Colorado twins were approached by mail or phone and 86% agreed to participate in the study. Parents in Australia and Scandinavia were approached by mail with a participation rate of 60%. 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).

Preschool measures of prereading skills

A total of 19 tests were employed to assess prereading skills at preschool age. These measures were then grouped into six composite measures of prereading skills based on prior factor analyses and theoretical considerations

Table 1. Mean age (standard deviation within parenthesis) and total preschool sample size by country, zygosity, and sex

	Australia	U.S.	Scandinavia
Age (in months)	57.7 (3.6)	58.8 (2.3)	61.2 (1.8)
Total sample (pairs)	183	488	138
MZ twins	111	225	65
Same-sex DZ	72	263	73
MZ females	53	128	33
MZ males	58	97	32
DZ females	33	117	36
DZ males	39	146	37

(Samuelsson et al., 2005). Composite measures were created by calculating the sum of age- and gender-adjusted *z* scores for each pre-school measure underlying each of the six composite measures. This sum was then divided by the number of tests included in each composite score. Standardization of each measure was performed across twin samples for mean comparisons and within each twin sample for correlation analyses. The prereading skill categories were also modeled as latent traits derived from their individual measures, standardized within sample, for our behavior genetic analyses. More detailed descriptions of all measures are available in Byrne et al. (2002) and Samuelsson et al. (2005).

Phonological awareness
A total of six measures of phonological awareness were employed in the study. The tasks varied in linguistic complexity by emphasizing words, syllables, or phonemes, and in cognitive demands by stressing blending, elision, rhyme, or sound matching. Three tests, syllable and phoneme blending, word elision, and syllable and phoneme elision were all made available by Lonigan (personal communication, 2000). The test of sound matching was derived from the Comprehensive Test of Phonological Processes (CTOPP; Wagner, Torgesen, & Rashotte, 1999). In the rhyme and final sound test, children were asked to recognize rhymes (10 trials), or final phoneme (6 trials). In these five tests, practice items preceded each test and feedback was provided by the experimenter after each practice trial. Reliabilities indicated by Cronbach's α varied between .49 and .77 with an average reliability of .69. In the final task, we also employed a dynamic measure of phonological awareness implemented by gradually increasing instructional support and feedback in four different stages while the child was asked to identify either the initial (two subtests) or final (two subtests) sound in words (see Byrne et al., 2002; Samuelsson et al., 2005, for more details). This dynamic task of phonological awareness was administered in four out of five sessions of testing, starting with initial /s/ on Day 2, initial /p/ on Day 3, final /l/ on Day 4, and final /t/ on Day 5. The average percentage of correct responses across all four phonemes were used as a dependent measure. Cronbach's α was .81 for this task.

Rapid naming
The Rapid Object naming and Rapid Color Naming subtests from the CTOPP (Wagner et al., 1999) were used as two measures of naming speed. Cronbach's α was .71 for object naming and .81 for color naming.

Verbal memory

Three memory tasks were used to calculate a composite measure of verbal memory: the Story Memory subtest from WRAML (Adams & Sheslow, 1990), Sentence Memory from the WPPSI battery (Wechsler, 1989), and the nonword repetition task developed by Gathercole, Willis, Baddeley, and Emslie (1994). Cronbach's αs were approximately .85 for all three tasks.

Vocabulary

The vocabulary subtest from the WPPSI battery (Wechsler, 1989) and the Hundred Picture Naming Test (Fisher & Glenister, 1992) were employed to create a composite measure of vocabulary. Test-retest reliability in 4.5 years olds is reported to be .83 for the vocabulary subtest from the WPPSI battery, and Cronbach's α was .89 for the picture naming test.

Grammar/morphology

The composite measure for grammar and morphology was calculated based on two tasks. Grammatical knowledge was measured by the Grammatic Closure subtest from the Illinois Test of Psycholinguistic Abilities (McCarthy & Kirk, 1961). A test of productive morphology based on Berko (1958) was used to measure morphological ability. Cronbach's αs were .88 and .89, respectively.

Print knowledge

The composite measure of print knowledge was composed by four tasks: Letter recognition from names and sounds, concepts about print (Clay, 1975), and a test of environmental print exposure. Cronbach's αs were .92 and .87 for letter recognition from names and sounds, .83 for concepts about print, and .46 for environmental print.

Preschool measures of the home literacy environment

To measure print environment specific to each twin in a family at the time of preschool testing, we used two questionnaires comprising a total of 19 questions (Griffin & Morrison, 1997; Whitehurst, 1992). Based on a factor analysis, these questions were grouped into four composite measures of home literacy environment (see Samuelsson et al., 2005): Shared book reading, letter-based activities, print motivation, and parent reading behavior. Parent level of education was included as a fifth environmental factor.

Reading and spelling tests at the end of kindergarten

All four subtests from the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999), which includes both real and pseudoword items in forms A and B, were used to create composite measures of word decoding and word recognition. In addition, for the behavior genetic analyses, we modelled the word and nonword reading efficiency skills as latent traits based on the different forms for each measure. Spelling was measured by a test developed by Byrne and Fielding-Barnsley (1993) including ten simple words and four nonwords, with both phonological and orthographic accuracy contributing to the score.

Testing procedures

Informed consent was obtained in writing from all of the families who agreed to take part in the study. Preschool testing was performed at home or in preschool, and all tests were administered individually to each child. The children were tested on 5 days over a 1 or 2 week period, and each test session took approximately 1 hour. Each twin pair was tested at the same time by two different experimenters in Australia and the U.S, while one tester assessed both twins in Scandinavia. Follow-up testing of literacy and other skills at the end of kindergarten was conducted with separate testers for each twin in their home during a single 1-hour session.

Analyses

One-way analyses of variance (ANOVA) and Tukey HSD post hoc tests were performed to test the significance of the differences between twin samples for composite measures of prereading skills and environmental factors. The magnitude of the mean differences was calculated using Cohen's *d*. Cohen's *d* can be interpreted in terms of the percent of non-overlap in two distributions. An effect size of .20 indicates an overlap of 85.3% in the distribution of two samples and is considered to be rather small. An effect size of .50 is considered to be only moderate since there is still a 67% overlap in the distribution of two samples. For this reason, we decided to treat mean differences with an estimated effect size above .50 as indicating meaningful differences between the samples that merit discussion. Pearson correlations were calculated to analyze phenotypic correlations among prereading skills within twin samples. Patterns of genetic and environmental influences on prereading skills and early reading and spelling skills within twin samples were analyzed using MZ and DZ twin correlations, and by Mx modelling of the variance/covariance matrices for MZ and DZ twins (Neal, Boker, Xie, & Maes, 2002).

Results

Sample means and variances in preschool print environment

Descriptive statistics for each environmental factor and effect size estimates for mean differences between twin samples are presented in Table 2. There were significant mean differences between Scandinavia on the one hand and Australia and the U.S. on the other hand for shared book reading and letter-based activities. Mean differences on print motivation, parent reading behavior, and parents' level of education did not reach significance. The Australian and the U.S. twin samples were comparable on all five environmental factors.

The pattern of sample differences in shared book reading and letter-based activities supports our hypothesis that parents in Scandinavian countries are less eager to involve children in literacy activities. It seems unlikely that the Scandinavian parents' own reading behavior or their average level of education contribute to this difference, since there were no significant sample differences on these measures. Child-initiated activities indexed by their print motivation are also comparable between twin samples. Thus, a common historical and cultural tradition in the Scandinavian countries unified by similar languages seems to have a substantial impact on how and when informal literacy socialization takes

Table 2. Means, standard deviations, and effect size estimates for differences between samples for composite measures derived from the family reading questionnaires

Variable	Australia	U.S.	Scandinavia	d^1	d^2	d^3
Shared book reading	.16 (.47)	.14 (.56)	−.56 (.49)	.03	1.2*	1.2*
Letter-based activities	.06 (.61)	.14 (.59)	−.39 (.74)	−.06	.68*	.74*
Print motivation	.14 (.70)	−.05 (.73)	.02 (.76)	.26	.16	−.09
Parent reading behavior	−.14 (.55)	.05 (.67)	.07 (.60)	−.31	−.36	−.03
Parents' level of education	−.21 (.77)	.08 (.95)	−.01 (1.2)	−.35	−.21	.08

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.
*$P < .001$.

place. Although Scandinavian countries are often perceived as having relatively homogeneous populations compared to other western countries, the very similar within-sample standard deviations on all five environmental measures shown in Table 2 suggests that the environmental ranges are similar across samples.

Sample means and variances in prereading skills

Table 3 presents means, standard deviations, and effect-size estimates for composite measures of prereading skills for the three twin samples. Analyses of variance (ANOVA) with twin samples as the between-group factor indicated significant sample differences for 5 out of 6 composite measures. The Australian twin sample performed significantly better than both the U.S. and the Scandinavian twin samples on phonological awareness, verbal memory, and vocabulary. In addition, the Australian twin sample performed significantly better than Scandinavian twins on rapid naming and print knowledge. Significant mean differences between U.S. and Scandinavian twin samples were also obtained for rapid naming and print knowledge. However, mean differences with effect sizes above .5 seem to cover two main areas of prereading skill. First, Scandinavian twins performed substantially lower on print knowledge compared to both Australian and U.S. twins. A second set of large effect sizes indicated that Australian twins possessed vocabulary abilities substantially above those found in the U.S. and Scandinavian samples.

Table 3. Means, standard deviations, and effect size estimates for differences between samples for composite measures of prereading skills

Composite measure	Australia	U.S.	Scandinavia	d^1	d^2	d^3
Phonological awareness	.19 (.69)	−.02 (.68)	−.13 (.70)	.30*	.46*	.16
Rapid naming	.05 (.87)	.08 (.84)	−.19 (.83)	−.04	.28*	.32*
Verbal memory	.23 (.72)	−.02 (.73)	−.19 (.82)	.34*	.53*	.22
Vocabulary	.59 (.74)	−.15 (.78)	−.22 (.86)	.97*	1.01*	.08
Grammar/ morphology	.08 (.90)	−.04 (.87)	.06 (.87)	.14	.02	−.11
Print knowledge	.18 (.77)	.08 (.75)	−.55 (.65)	.13	1.03*	.90*

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.

The mean difference in print knowledge between Scandinavia on the one hand and Australia and U.S. on the other hand indicating less than 50% overlap between the distributions is probably the result of differences in home literacy environment. Although the correlations between aspects of home literacy environment and the development of children's language and beginning reading skills are generally modest (Scarborough & Dobrich, 1994), in previous analyses of the combined samples we obtained correlations of .44 between print knowledge and shared book reading, and .32 between print knowledge and letter-based activities (Samuelsson et al., 2005). A similar explanation may apply for the mean difference in vocabulary between Australia and Scandinavia with an average correlation between home literacy activities and vocabulary of .25 in the combined sample. However, there is no obvious explanation for the difference in vocabulary between Australia and the U.S. One possible explanation might be that Australian parents were self-selected to be engaged in future twin research when they joined the twin registry, while both U.S. and Scandinavian families with twins were approached via the birth registry. On the other hand, Australian families were similar to those in the U.S. sample on all environmental measures including parents' mean years of education.

Within-sample correlations among prereading skills

The correlations among all composite measures of prereading skills are presented separately for each sample in Table 4. This table shows the uniformly significant correlations among all composite measures of prereading skills across all three twin samples. However, the correlations between rapid naming and the remaining five measures of prereading skills are in most cases below .30 indicating that less than 10% of the variance in rapid naming at pre-school age overlaps with the variance of the language and memory measures. This pattern of low phenotypic correlations between rapid naming and the remaining prereading skills is close to identical across twin samples. Further inspection of Table 4 reveals that phonological awareness correlates with memory and language skills at approximately .50 and this pattern of correlations is also similar across twin samples. The highest correlations between phonological awareness and the remaining prereading skills across twin samples are found between phonological awareness and print knowledge (.60, .65, and .54 for Australia, U.S., and Scandinavia, respectively). Similar patterns of correlations across twin samples are also found between verbal memory, vocabulary, and grammar/morphology, with

Table 4. Correlations among composite scores for (a) Australian, (b) U.S., and (c) Scandinavian twin samples

Composite measure	1	2	3	4	5	6
(a)						
1 Phonological awareness	1.00					
2 Rapid naming	.30	1.00				
3 Verbal memory	.49	.24	1.00			
4 Vocabulary	.47	.29	.55	1.00		
5 Grammar/morphology	.59	.23	.51	.60	1.00	
6 Print knowledge	.60	.32	.37	.50	.56	1.00
(b)						
1 Phonological awareness	1.00					
2 Rapid naming	.28	1.00				
3 Verbal memory	.54	.25	1.00			
4 Vocabulary	.58	.23	.65	1.00		
5 Grammar/morphology	.59	.22	.66	.65	1.00	
6 Print knowledge	.65	.32	.45	.58	.53	1.00
(c)						
1 Phonological awareness	1.00					
2 Rapid naming	.34	1.00				
3 Verbal memory	.49	.30	1.00			
4 Vocabulary	.51	.38	.61	1.00		
5 Grammar/morphology	.52	.31	.56	.51	1.00	
6 Print knowledge	.54	.39	.43	.53	.41	1.00

average correlations at .55 in Australia, .65 in the U.S., and .56 in Scandinavia. Across twin samples and across all correlations, the largest difference was obtained for the correlation between verbal memory and grammar/morphology in Australia (.51) compared to the U.S. (.66).

In summary, the phenotypic analyses revealed significantly lower print knowledge in the Scandinavian sample that was related to significantly less emphasis on print in their environment. However, the within-sample standard deviations for the measures of print environment and prereading skills were similar across samples, and the within-sample correlations among prereading skills were also similar across samples. This led to our hypothesis that estimates of genetic and environmental influences on prereading skills might also be similar across samples.

Sample comparisons of genetic and environmental influences on prereading skills

MZ and DZ twin correlations for the prereading skill composite measures are presented separately in Table 5 for the Australian, U.S., and Scandinavian samples. Although the MZ correlations were always higher than the DZ correlations for all measures in all samples, suggesting genetic influences, the size of the differences between the MZ and DZ correlations seemed to vary in largely similar patterns within the samples. For example, in all samples, there were larger differences between MZ and DZ correlations for phonological awareness, rapid naming, and verbal memory (suggesting strong genetic influences), compared to more similar and high MZ and DZ correlations for vocabulary and print knowledge (suggesting strong shared environment influences).

The results of Mx analyses of the MZ and DZ twins' variance/covariance matrices for estimates of genetic (a^2), shared environment (c^2), and non-shared environment (e^2) on the latent traits for each skill are presented separately for each sample in Table 6, with 95% confidence intervals in parentheses. The largely consistent pattern across samples implied by the MZ and DZ twin correlations in Table 5 is confirmed by the pattern of Mx estimates in Table 6. For all samples, estimates of genetic influence exceeded estimates of shared environment influence for phonological awareness, rapid naming, and verbal memory, while estimates of shared environment influence exceeded estimates of genetic influence for vocabulary and print knowledge. The only departure from this shared pattern across samples was for grammar/morphology, where genetic influence was slightly stronger than shared environment influence for the Australian sample.

Table 5. Intraclass twin correlations for composite measures across samples

Composite measure	Australia		U.S.		Scandinavia	
	MZr	DZr	MZr	DZr	MZr	DZr
Phonological awareness	.70	.36	.80	.51	.74	.44
Rapid naming	.64	.39	.64	.40	.73	.35
Verbal memory	.63	.26	.71	.50	.81	.54
Vocabulary	.59	.52	.76	.63	.83	.72
Grammar/morphology	.67	.44	.71	.58	.81	.59
Print knowledge	.75	.63	.82	.70	.88	.77

Table 6. MX model fitting estimates (and confidence intervals) for latent traits of pre-reading skills for the entire sample of twins and within each twin sample

Composite measures	a^2	c^2	e^2
Phonological awareness			
U.S. twins	.58 (.39, .80)	.34 (.13, .51)	.08 (.04, .13)
Australian twins	.64 (.19, .93)	.20 (.00, .60)	.15 (.07, .28)
Scandinavian twins	.46 (.02, .92)	.38 (.00, .74)	.16 (.06, .31)
Rapid naming			
U.S. twins	.58 (.29, .80)	.15 (.00, .39)	.27 (.20, .37)
Australian twins	.60 (.17, .88)	.17 (.00, .54)	.23 (.12, .37)
Scandinavian twins	.78 (.37, .88)	.00 (.00, .37)	.22 (.12, .35)
Verbal memory			
U.S. twins	.48 (.27, .70)	.41 (.21, .59)	.11 (.04, .19)
Australian twins	.87 (.55, .98)	.00 (.00, .28)	.13 (.02, .28)
Scandinavian twins	.58 (.24, 1.0)	.37 (.00, .67)	.05 (.00, .17)
Vocabulary			
U.S. twins	.26 (.02, .52)	.66 (.43, .85)	.08 (.01, .17)
Australian twins	.18 (.00, .64)	.50 (.05, .83)	.32 (.12, .54)
Scandinavian twins	.25 (.00, .65)	.70 (.32, .96)	.05 (.00, .18)
Grammar/morphology			
U.S. twins	.32 (.10, .56)	.55 (.33, .73)	.13 (.06, .21)
Australian twins	.45 (.00, .96)	.41 (.00, .81)	.14 (.00, .30)
Scandinavian twins	.20 (.00, .59)	.72 (.36, .97)	.08 (.00, .23)
Print knowledge			
U.S. twins	.26 (.13, .41)	.65 (.51, .76)	.09 (.06, .14)
Australian twins	.25 (.00, .59)	.62 (.30, .84)	.13 (.07, .22)
Scandinavian twins	.20 (.00, .44)	.74 (.51, .89)	.07 (.02, .14)

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

The confidence intervals for the estimates in Table 6 are particularly large for the Australian and Scandinavian samples, each having less than half the number of twin pairs contained in the U.S. sample with its more narrow confidence intervals. This obviously limits our ability to assert that there are no differences in genetic and environmental profiles for the different measures across samples. Planned further expansion of the samples will narrow the confidence intervals, but of course we will never be able to claim the null hypothesis that there are no differences between samples. All we can claim at present is that the varying estimates among the different preschool measures are remarkably similar across the samples.

Table 7. Means, standard deviations, and effect size estimates for differences between U.S. and Australian twin samples for reading and spelling skills near the end of kindergarten

Literacy measure	Australia	U.S.	*d*
Phonological decoding	17.9 (15.6)	9.7 (12.0)	0.59*
Word recognition	38.7 (28.4)	22.9 (24.5)	0.59*
Spelling	63.3 (15.2)	49.7 (20.9)	0.74*

Note: d = Effect size for the difference between Australia and U.S.
*$P < .001$.

Sample comparisons of means and variances for reading and spelling skills in the U.S. and Australia at the end of kindergarten

Our hypothesis that Australian twins would exhibit reading and spelling skills at a higher level compared to U.S. twins at the end of kindergarten was confirmed. Significant advantages for the Australian sample were consistently found for raw scores in phonological decoding efficiency (18 vs. 10), word reading efficiency (39 vs. 23), and spelling (63 vs. 50) (see Table 7). However, our hypothesis that the stronger and presumably more consistent emphasis on teaching reading and spelling in Australian kindergartens might contribute to reduce the variances in reading and spelling in the Australian sample compared to the U.S sample was not confirmed. Instead, the standard deviations observed for phonological decoding and word reading efficiency raw scores were slightly though not significantly lower in the U.S. sample compared to the Australian sample, and the standard-score standard deviations were nearly identical between countries.

Sample comparisons of genetic and environmental influences on kindergarten reading and spelling

Mx estimates of genetic and environmental influences on word reading efficiency, nonword reading efficiency, and spelling are presented separately in Table 8 for the Australian and U.S. samples. These estimates suggest substantially stronger genetic influences on these skills in the Australian sample. We emphasize that these results are only suggestive, because the confidence intervals with the current small sample sizes for twins tested at the end of kindergarten (157 Australian pairs and 312 U.S. pairs) are large and overlapping, even for the large differences in a^2

Table 8. MX model fitting estimates (and 95% confidence intervals) for nonword decoding, word recognition, and spelling near the end of kindergarten

Literacy measures	a^2	c^2	e^2
Phonological decoding			
U.S. twins	.49 (.30, .71)	.35 (.14, .53)	.16 (.12, .22)
Australian twins	.88 (.57, .91)	.00 (.00, .29)	.13 (.09, .19)
Word recognition			
U.S. twins	.61 (.45, .81)	.33 (.12, .49)	.07 (.05, .09)
Australian twins	.91 (.67, .94)	.00 (.00, .24)	.09 (.06, .13)
Spelling			
U.S. twins	.34 (.11, .59)	.46 (.23, .65)	.20 (.13, .29)
Australian twins	.84 (.53, .91)	.00 (.00, .31)	.16 (.09, .22)

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

estimates for nonword reading efficiency and spelling. There were also substantial differences in the sample estimates of shared environment influences on nonword reading efficiency and spelling, though again the confidence intervals were too large to yield statistically significant contrasts between samples.

Discussion

In the present study we explored how our Australian, U.S., and Scandinavian preschool samples compared in their means, variances, and correlations for measures of their early literacy environment and important prereading skills. Then we compared the three samples' genetic, shared environment, and non-shared environment estimates for individual differences in prereading skills. Finally, we explored the means, variances, and estimates of genetic and environmental influences on reading and spelling skills in the Australian and U.S. samples that had been retested at the end of their kindergarten year. The Scandinavian sample was not included in this follow-up analysis of reading and spelling skills because most of the children in that sample could not read or spell any words.

Parent questionnaire assessments of their own reading behavior and years of education were highly comparable across all three twin samples, but parent-initiated literacy activities such as shared book reading and letter-based activities were significantly less frequent in the Scandinavian sample. These differences were expected because of the tradition in both Sweden and Norway of emphasizing social and emotional competencies at preschool instead of activities aimed at providing foundation skills in reading and spelling. In spite of the significant mean differences between samples, variation in home literacy practices within countries was similarly related to prereading skills, particularly print awareness and vocabulary across all three samples. These relations helped explain why Scandinavian twins performed approximately one standard deviation below the twins in Australia and U.S. on the composite measure of print knowledge.

A novel question examined in this study was to what extent genetic and environmental influences on prereading skills were comparable across twin samples, and also across two languages. Phenotypic analyses revealed similar variances for the environmental measures and prereading skills across the three samples, so in spite of the samples' substantial mean differences in print environment, print knowledge, and vocabulary, there apparently were no significant differences in the samples' environmental range that might contribute to sample differences in the estimates of genetic and environmental influences on prereading skills.

Patterns of differences between MZ and DZ twin correlations for composite scores and Mx parameter estimates of genetic and environmental influences on latent traits revealed that in all three samples, print knowledge and vocabulary showed moderate heritability and strong influences from shared environment. On the other hand, phonological awareness, verbal memory and rapid naming showed substantial heritability and lower influences from shared environment. In the results section we acknowledged that the confidence intervals for the Australian and Scandinavian samples' Mx parameter estimates for genetic and environmental influences on prereading skills were quite large due to their small sample size, but we argued that the three samples' highly similar patterns of genetic and environmental influences across the different prereading skills provided further support for the similarity of genetic and environmental etiologies of prereading skills across the three samples. Thus, these results provide support for combining the preschool samples to achieve greater statistical power in our univariate and multivariate analyses of prereading skills (Byrne et al., 2002, 2005, 2006; Samuelsson et al., 2005).

Another interesting perspective is to compare present findings with more recent cross-language literature. The numbers of studies examining differences in reading and spelling acquisition across two or more languages have increased considerably in the last few years. Normally these studies compare literacy acquisition across examples of deep and shallow orthographies, or across different writing systems (Perfetti, 2003). Although there are differences in the rate of learning to read in different orthographies and differences in the strategies in decoding different writing systems, there seem to be basic principles based on the relation between spoken language and writing systems that are universal across writing systems (Perfetti, 2003). Similarly, reading in different languages seems to involve the same underlying cortical systems across different alphabetic orthographies (Paulesu et al., 2001), and to some extent across different writing systems (Liu, Dunlap, Fiez, & Perfetti, 2005). Our findings suggesting similar patterns of MZ and DZ twin correlations and parameter estimates of genetic and environmental influences on prereading skills across countries and languages suggest that the origin of individual differences in foundation skills for literacy development are universal across languages, although it remains to be seen if this situation continues to hold later in schooling.

The first follow-up evaluation of emerging reading and spelling skills in the ILTS samples takes place at the end of the kindergarten year. During the kindergarten year, there are significant sample differences in their emphasis on formal literacy instruction, and these differences are consistent with the samples' significant mean differences in reading and spelling that we found at the end of kindergarten. With virtually no formal literacy instruction during the Scandinavian kindergarten year, most children could not read or spell any words. Kindergarten literacy instruction and class time in the U.S. varies across the states. In Colorado kindergartens, there is variable emphasis on early literacy instruction and children typically attend kindergarten for only half days. In New South Wales, there is a state kindergarten curriculum for literacy instruction and children attend kindergarten for full days. Therefore we expected that reading and spelling scores would be significantly higher for the Australian sample, and we also expected that the variance in scores would be higher for the Colorado sample. The first expectation was confirmed, but the second expectation was not, since the raw-score variance was slightly higher in the Australian sample, and the standard-score variances were nearly identical.

Following our phenotypic analyses of the sample means and variances for reading and spelling at the end of kindergarten, we conducted behavior genetic analyses within the Australian and Colorado samples, where there was sufficient sample size and comparable variance estimates (the Scandinavian sample was too small and reading was too low for these analyses). In contrast to the generally similar patterns of genetic and environmental influence for prereading skills across the samples, there were some large sample differences in the genetic and shared environment estimates for reading and spelling. There were much stronger genetic influences on nonword reading efficiency, word reading efficiency, and spelling in the Australian sample compared to the U.S. twin sample. The largest sample difference was found for spelling, where the 95% confidence intervals for genetic and shared environment influences indicate nearly significant contrasts between the samples.

What are the reasons for the sample differences in genetic and environmental influences on reading and spelling at the end of kindergarten? The finding that the variances for reading and spelling were comparable between the two samples did not support our hypothesis that the national literacy curriculum in Australian kindergartens would result in a narrower environmental range and less variance compared to the Colorado sample. Therefore, we hesitate to argue that genetic influence was lower and shared environment influence higher because of greater environmental range in the Colorado sample. On the other hand, the more limited literacy instruction in Colorado kindergartens may have meant that the earlier variance in the twins' preschool print knowledge, mostly due to shared environment, was continuing to influence variation within their lower range of reading and spelling scores at the end of kindergarten. In contrast, although the Australian preschool twins' similar variance in print knowledge was also mostly due to shared environment, their subsequent response to a more intense, lengthy, and consistent kindergarten program of reading and spelling instruction became the dominant influence on their reading scores. We have noted that the variation in response to consistent and intensive literacy related instruction can be broad (see Byrne, Fielding-Barnsley, & Ashley, 2000), and we hypothesize that individual differences in response to instruction may be largely influenced by genes. This hypothesis is given some support by the apparent increase in genetic influence and decrease in shared environment influence on individual differences in reading and spelling when a subset of the Colorado twins were tested again on the same reading efficiency measures at the end of first grade (Byrne et al., this volume). The hypothesis is also supported by the analyses of Petrill, Deater-Deckard, Thompson, Schatschneider, and Dethorne (this volume) in their Midwest U.S. twin sample for a measure of reading comprehension. Their estimate of genetic influences on reading comprehension among twins that were first tested near the end of kindergarten were low compared to estimates from twins initially tested in first or second grade.

It is interesting to think about how these results relate to the increasing emphasis in the U.S. on response to intensive systematic instruction as a basis for diagnosing and hopefully remediating reading disabilities (Lyon, Fletcher, Fuchs, & Chhabra, in press; Vellutino & Fletcher, 2005). It appears that within-sample variation in response to systematic regular school-based instruction is largely influenced by genes by the end of kindergarten in Australia and by the end of first grade in the U.S., as long as there are not a lot of extreme literacy-instruction differences for twins within the sample or other environmental constraints such as learning to read in a second language (Olson, 2004). However, this does not imply genetic determinism. The substantial mean reading and spelling differences between children in Australia, Colorado, and Scandinavia at the end of kindergarten show that instruction matters (though the superior reading of Scandinavian children in the later grades reported in the Organization for Economic Cooperation and Development (OECD; 2002) study suggests its timing is not critical), regardless of any genetic influence on individual differences in rate of response to that instruction. Thus, the reading performance distribution in a population can be moved to higher levels by a greater emphasis on reading instruction (and reading practice), as is currently being done in many U.S. schools, even if genes are largely responsible for individual differences in response to that instruction. But again, this does not imply complete genetic determinism for a child's low position within the population distribution, if that child is given sufficient supplemental instruction and reading practice. In fact, this is the recommended procedure in programs for children whose slow rate of response to quality instruction in the schools has substantially compromised their progress in reading (Lyon et al., in press).

We conclude by repeating our acknowledgement of an important limitation in the present analyses of sample differences in genetic and environmental influences. The small current size of the samples, particularly in Australian and Scandinavia, has led to large confidence limits for the genetic and environmental parameter estimates within each sample. Although the estimates were generally similar across samples for pre-reading skills, the large confidence intervals limit our confidence that there are no major differences. Nor can we be certain that the large sample differences in estimates for genetic and environmental influences on reading and spelling skills at the end of kindergarten are real differences. Further expansion of the samples in Australia, the U.S., and Scandinavia will eventually support more statistically powerful between-country comparisons of genetic and environmental influences, as these may differ due to variation in cultural, linguistic, educational homogeneity, and educational level within countries. At present, the strongest evidence for country differences in both mean performance and genetic influence seems to be due to variation in the amount of formal literacy instruction in kindergarten, and the related difference in opportunity to observe genetic influences on individual differences in response to that instruction.

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