HHS Public Access

Author manuscript

J Learn Disabil. Author manuscript; available in PMC 2019 November 23.

Published in final edited form as:

J Learn Disabil. 2019 ; 52(2): 135–145. doi:10.1177/0022219418775116.

Genetic and Environmental Influences on Achievement Outcomes Based on Family History of Learning Disabilities Status

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Previous work shows that the risk for children to develop a learning disability is increased substantially if there is a family history of learning disability (Vogler, DeFries, & Decker, 1985; Snowling & Melby-Lervåg, 2016). Specifically, children with a family history of reading disability/dyslexia are four times more likely to have a reading disability than peers with no such family history (Snowling & Melby-Lervåg, 2016). Furthermore, a positive family history status has been shown to be a predictive risk index for estimating a child's prospective risk for reading disability (Catts, Fey, Zhang, & Tomblin, 2001; Puolakahano et al., 2007; Snowling, Gallagher, & Frith, 2003; Thompson et al., 2015). In addition, prior research has indicated that children with a family history of learning disability fall behind children with no family history in achievement outcomes. For example, significant mean differences have been indicated for word and nonword reading (Snowling, Gallagher, & Frith, 2003), reading comprehension (Cardoso-Martins & Pennington, 2004; Elbro & Petersen, 2004; Snowling, Gallagher, & Frith, 2003), and spelling (Snowling, Gallagher, & Frith, 2003) in that children with a family history of reading disability scored lower compared to children with no such family history. Similar to reading and spelling, children with a family history of math disability are more likely to have persisting difficulties in math compared to children with no family history (Fletcher, Reid Lyon, Fuchs, & Barnes, 2007). Overall, it is well established that there is familial transmission of learning disabilities (van Bergen, van der Leij, & de Jong, 2014a; Snowling & Melby-Lervåg, 2016), which reflects in higher likelihood of developing a learning disability and, thus, in lower achievement scores for children with a family history for learning disability compared to their peers with no such family history.

Given the potential role of family history status for improving prediction of achievement outcomes, it is important to understand whether the genetic and environmental effects on

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these achievement outcomes vary as a function of family history status. Differences could be due to genetic and/or environmental factors. Under a simple genetic view of family history, parents with a learning disability pass on gene loci to children that confer a genetic liability or susceptibility to develop a learning disability. However, family history also refers to the environment, and parents with a learning disability may create less advantageous home (learning) environments. Therefore, an important question is whether genetic and environmental factors are equally important in contributing to individual differences in achievement outcomes based on children's family history status. Achievement outcomes are in the present study defined as academic scores on the measures of reading, spelling, and math.

There has been a substantial and consistent behavior genetics literature examining the roles of genetic influences on developing a learning disability. Both the generalist genes hypothesis (Plomin & Kovas, 2005; Kovas & Plomin, 2007) and Pennington's multiple deficit model of disability (Pennington, 2006) suggest that overlapping genetic influences underlie both learning abilities and disabilities. More specifically, "the liability distribution for a given disease is often continuous and quantitative, rather than being discrete and categorical" (Pennington, 2006, p. 404), thus implying cutoffs between abilities and disabilities are somewhat arbitrary. This would suggest that the genetic estimates for ability and disability would be the same. In addition, results of a combined twin-family study showed that parents and children tend to resemble each other for learning (dis)ability, specifically, for reading (dis)ability, due to genetic reasons (Swagerman et al., 2015). Also, analyses of twin samples demonstrate that both learning ability and disability are moderately to strongly heritable across the distribution. For example, results have indicated that 50–70% of variance in reading problems is associated with genetic factors (Grigorenko, 2004). Similarly, average heritability for reading ability is estimated at $h^2 = .59$ (for a review see Little, Haughbrook, & Hart, 2017). The influence of genetic factors appears to be moderate to strong also for other learning (dis)abilities. Math disability tends to be moderately affected by genetic factors ($h_g^2 = .38–.69$) (Alarcón, DeFries, Light, & Pennington, 1997; Oliver et al. 2004; Hart, Petrill, & Dush, 2010), and so does math ability (math fluency) ($h^2 = .34–.63$) (Hart, Petrill, Thompson, & Plomin, 2009; Hart et al., 2010; Petrill et al., 2011). Moderate estimates for heritability have been also found for spelling ($h^2 = .51–.54$) (Byrne et al., 2008; Bates et al., 2007). Taken together, according to the generalist genes hypothesis (Plomin & Kovas, 2005) and multiple deficit model (Pennington, 2006), individual differences based on family history status might not necessarily translate into etiological (genetic and environmental) differences in achievement outcomes, although this hasn't been explicitly tested.

Beyond genetic factors, various environmental factors have also been shown to be important in the development of learning (dis)abilities, in particular in literacy and numeracy skills (Burgess, Hecht, & Lonigan, 2002; LeFevre et al., 2009). They have been proposed to account for individual differences in achievement outcomes. One such environmental factor is home-based parental learning environment that includes facets such as home literacy and numeracy environment. The home literacy environment - a term used to describe literacy activities parents engage in with their children (Sénéchal & LeFevre, 2002; see also Burgess et al., 2002) - has received much attention in the literature with regard to its positive

association with achievement outcomes. Far less research is on home numeracy environment. Nevertheless, it has been suggested that home numeracy experiences are related to children's acquisition of math (LeFevre et al., 2009). However, as to the role of home learning environment on achievement outcomes of children with a family history and children with no family history, mixed findings have been reported. Work by Scarborough (1991) found that children with a family history who developed dyslexia were read to less often by their fathers than children with no family history. For mothers, there was less joint reading for children with a family history at 30 months than for children with no family history but not thereafter (Scarborough, 1991; Snowling & Melby-Lervåg, 2016). Similarly, a more recent study by Dilnot and colleagues (2017) showed that home literacy environment explained variance in reading outcome over and above a child's own cognitive skills. On the other hand, other studies have not found associations between home learning environment (e.g., shared reading, access to reading material, parental print exposure) and children's reading status in primary school (Torppa et al., 2007; van Bergen et al., 2014a).

While evidence suggests that home learning environment might be important for individual differences in achievement outcomes for children based on their family history status, an important next step will be to more specifically delineate the role of home learning environment as an environmental factor for children based on their family history status. If home learning environment for reading, math, and other achievement outcomes is poorer for children with a family history, then environmental influences would be more important/stronger for these children compared to children with no family history, because the poor environment could be the main reason for the failure of children with family history. On the other hand, environmental influences would be less important/weaker among children with no family history because there is greater actualization of genetic potential in supportive environments than in poor environments. Such a scenario would be consistent with a bioecological model (Bronfenbrenner & Ceci, 1994). While the environmental-disadvantaged hypothesis also predicts constrained heritability in impoverished environments (Scarr-Salapatek, 1971), the bioecological model extended this prediction across the environmental range. However, if environmental influences for reading, math, and other achievement outcomes are less important/weaker in poorer home learning environments (environments of children with a family history), that would imply that stressors, such as poor environment of children with a family history may lead to the expression of deleterious genes on behavior (reading or other learning disabilities) that would otherwise not be observed in more supportive environments. Such a scenario would be supportive of the diathesis-stress model (Scarr, 1992). Both scenarios are plausible. Overall, research suggests that environmental factors, such as home learning environment, might partly explain mean differences in achievement scores between children with a family history for learning disabilities and children with no such history. According to this work, mean differences could translate into etiological differences on achievement outcomes for children based on family history status.

The twin study method is a powerful approach for answering the question of whether genetic and environmental factors are equally important for individual differences in various achievement outcomes for children with a family history of learning disability and children with no such family history. This method decomposes the observed variance into genetic and

environmental components of variance (Plomin, DeFries, McClearn, & Rutter, 1997). This decomposition of variance can then be calculated separately for children with a family history of learning disability and children with no family history in order to examine etiological differences (heritability, shared and non-shared environment) between the two subgroups and elucidate whether genetic or environmental parameters are relatively more important in one subgroup than the other. Heritability (h^2) refers to the proportion of variance attributable to genetic influences, shared environment (c^2) to the environmental influences that are common to siblings and make them more similar, and non-shared environment (e^2) to the unique environmental effects that make siblings different (as well as measurement error).

The goal of this report was to investigate genetic and environmental influence on achievement outcomes (reading, spelling, and math) in two subgroups based on family history for a learning disability status, and assess the presence of possible etiological differences in achievement outcomes between the two subgroups. The present report is the first to determine possible etiological differences in achievement outcomes based on a family history. Based on the work by Plomin and Kovas (2005), and Pennington (2006), we didn't expect to find etiological differences across achievement outcomes between the two subgroups. However, based on the work examining environmental effects on achievement outcomes (e.g., Scarborough, 1991), there could be etiological differences between the two subgroups. In this case, two scenarios are possible. First, we would expect to find greater magnitude effects for shared environment in twins with a family history of disability as compared to twins with no family history (for whom genetic influences would be predicted to show greater effects). Such an outcome would be in line with the bioecological model. Second, a hypothesis consistent with the diathesis-stress model would predict greater magnitude effects for genetic factors in twins with a family history of disability relative to twins with no family history (for whom shared environmental effects would be expected to show greater influences). Based on the fact that all models have received support in prior studies, no a priori hypothesis is offered.

Method

Participants

Participants for this study were twin pairs from the Florida Twin Project on Reading, Behavior, and Environment (FTP-RBE; Taylor, Hart, Mikolajewski, & Schatschneider, 2013). The present study used data from 174 monozygotic (MZ; 94 female-female pairs, 80 male-male pairs) and 262 dizygotic twin pairs (DZ; 103 female-female pairs, 78 male-male pairs, and 81 opposite sex). The twin pairs were in grades 4 through 10 in school year 2013–2014, with an average age of 13 years and 4 months (M = 13.30, SD = 1.40, range = 10.72 – 17.03). Zygosity of the twin pairs was determined by a parental five-item questionnaire obtained during intake into the FTP-RBE. These 872 twins represented all twins whose data were available on the family history questionnaire. Twins' parents or caregivers (parents hereafter) reported that 2.5% of the twins from the sample in the current study were Asian, 12.4% Black, 0.2% Native Hawaiian or Other Pacific Islander, 8.5% Mixed, 71.6% White, 3.9% Other and 0.9% did not report race. The percentages reported for race are somewhat

similar to values reported by the U.S. Census Bureau for the state of Florida (http://quickfacts.census.gov/qfd/states/12000.html). See Taylor et al. (2013) for additional information on the FTP-RBE and the ascertainment method.

Procedures and Measures

Standardized measures The Florida Assessment for Instruction in Reading (FAIR) Reading Comprehension and FAIR Spelling were collected by trained administrators as part of statewide achievement testing. Data were collected at multiple time points throughout the school years and entered into the Florida's Progress Monitoring and Reporting Network (PMRN) database, a statewide database of standardized achievement tests on children in schools throughout the state of Florida. Data from the spring collection period were used for this study. The rest of the measures were collected by mail. All parents of twins provided informed consent for investigators to use their twins' PMRN data and twins provided assent to participate as approved by the Florida State University Institutional Review Board.

Reading comprehension.—Reading comprehension was measured using a computer administered FAIR Reading Comprehension subtest. Students are asked to read one to three narrative or expository passages, and answer seven to nine multiple choice questions. The generic estimate of reliability from IRT ranges from .90 to .92 for grades 4 to 10 (http://www.fcrr.org/fair/Technical%20manual%20-%203–12-FINAL_2012.pdf).

Spelling.—FAIR Spelling subtest, called the Word Analysis Task, assesses students' orthographic knowledge. It is a computer administered test. Students listen to 5–30 items (i.e., words) depending on students' ability through the computer speakers or headphones. They respond by typing the combination of letters believed to spell the word correctly. Reliability scores from IRT are estimated at .92 to .95 for grades 4 to 10 (http://www.fcrr.org/fair/Technical%20manual%20-%203–12-FINAL_2012.pdf).

Math fluency.—Math fluency was measured by Math Fluency subtest of Woodcock-Johnson Test of Achievement. This subtest measures a student's ability to solve simple addition, subtraction and multiplication facts quickly. Students are given several sheets of simple math calculations and asked to respond accurately to as many items as possible in a three-minute time period. The 2001 test manual reports test-retest reliability of .95 for students aged 7–11 (http://www.hmhco.com/~/media/sites/home/hmh-assessments/clinical/woodcock-johnson/pdf/wjiii/wjiii_asb2.pdf?la=en).

Family History of Reading and Learning Difficulties.—Parents indicated in 9 items whether twins' biological mother/father/siblings (full or half) have had difficulties with reading/spelling/writing/math/language or have been diagnosed as having dyslexia/specific language impairment/autism/ADHD by placing a check in the box for each person the item applied to. In the present study, data on reported parent history (either of the biological parents) of having dyslexia or having difficulties in reading/spelling/math were used for analyses. Here only parents were being considered as parents provide their children with both genetic material and with home (learning) environments influencing children's achievement outcomes.

Data Analyses

Analyses comparing means and etiological differences in measures corresponding to a particular disability were conducted among two types of subgroups. (1) Twins having either of the parents reporting difficulties in reading, or spelling, or having dyslexia, arbitrarily labeled as twins with a family history of dyslexia (FH DYS+) versus twins having parents with no reporting difficulties in reading, or spelling, or having dyslexia, thus twins with no family history of dyslexia (FH DYS−). They were compared on a reading and on a spelling measure. (2) Twins having either of the parents reporting difficulties in math, thus twins with a family history of math disability (FH MATH+) versus twins having parents with no reporting difficulties in math, thus twins with no family history of math disability (FH MATH−). They were compared on a math fluency measure.

Aside from the abovementioned subgroups, additional subgroups were formed for the logistic regression models. (1) Twins with only mothers reporting difficulties in reading, or spelling, or having dyslexia. This group was arbitrarily labeled as twins who had a mother with dyslexia (FH MOM DYS+) versus twins with no affected mothers (FH MOM DYS−). (2) Twins with only fathers reporting difficulties in reading, or spelling, or having dyslexia (FH DAD DYS+) versus twins with no affected fathers (FH DAD DYS−). (3) Two other groups were created for twins with only one parent reporting difficulties in math. One group was defined as twins who had a mother with a math disability (FH MOM MATH+) versus twins with no affected mothers in math (FH MOM MATH−). (4) The other group was specified as twins with only fathers reporting difficulties in math (FH DAD MATH+) versus twins with no affected fathers in math (FH DAD MATH−).

Descriptive statistics were calculated for the total sample and for each type of subgroups for their corresponding achievement outcome (measure). Next, we compared the means between twins with a family history of disability and twins with no such family history for each achievement outcome using *t*-tests and Cohen's *d* effect sizes. Following that, a logistic regression modeling approach was employed to quantify the likelihood that twins would fall into the different FH subgroups (FH+ or FH−) given their scores on achievement measures. We thank an anonymous reviewer for this suggestion. For the logistic regression analyses, only one twin from each pair was randomly selected to ensure independence of observations.

Raw data on all measures for both twins in the pair were then residualized on age, age squared, and sex (McGue & Bouchard, 1984). Residualized data were subsequently *z*-scored. Intraclass correlations (ICC) for all achievement measures were calculated by zygosity for the whole sample and for family history of learning difficulties (FH) subgroups. All abovementioned analyses were conducted in SAS 9.4.

Following descriptive and inferential statistics, biometric modeling was used to decompose the total variance of each achievement measure into additive genetic (A), shared environmental (C) and non-shared environmental (E) influences. The A, C, and E parameter estimations were conducted separately for each FH+ and FH− subgroup, which resulted in a series of six univariate ACE analyses. Next, multi-group analyses were performed across FH subgroups for achievement measures corresponding to a particular disability. These were performed to test for possible etiological differences in achievement outcomes between the

two subgroups. Altogether, this resulted in conducting three separate multi-group analyses. First, a fully varying model (the unconstrained model), where A, C, and E estimates were allowed to vary by FH subgroup was tested, and then subsequently compared to a model were the A, C, and E estimates were invariant (the constrained model), or not allowed to vary across FH subgroups. If a chi-square difference test between these two models was non-significant, the constrained model was accepted and model testing stopped there. If a chi-square difference test indicated that there was a significant reduction in model fit after constraining across subgroups, it would be determined that there were FH subgroup differences in A, C, and/or E components of variance. As can be seen from our results, chi-square difference tests for all our models indicated that the constrained models be accepted, therefore we did not proceed with further multi-group model testing. Biometric analyses were fit using full information maximum likelihood in Mx (Neale, Boker, Xie, & Maes, 2006). Significance of parameter estimates was based on the 95% confidence intervals not including zero.

Results

Descriptive statistics, *t*-tests with Cohen's *d* effect sizes for all measures for the total sample as well as by FH subgroups are presented in Table 1. The *t*-test and effect size results comparing the means of the measure corresponding to a particular FH subgroup indicated significantly lower mean values for reading and spelling measures in twins with a family history of dyslexia. These differences were small to moderate. No significant differences between twins with a family history of math disability and no such family history were indicated for math fluency.

Table 2 presents results from the logistic regression analyses. Outcomes on all achievement measures were statistically significant indicators of FH+ status, as shown by the *p*-values. In general, FH+ status was negatively associated with academic achievement performance, such that the lower a twin scored on an achievement measure, the higher was his/her likelihood of a positive family history of disability. This was the case for all achievement outcomes, regardless of the density of family history (i.e., either of the parents or only one of the parents reporting having a learning disability).

Information from the logistic models, as shown in Table 2, was further utilized in building the probability curve presentations. They offer a powerful way to illustrate the extent to which high or low performance on an achievement measure is an indicator of a FH status, in terms of the estimated probability of a family history of disability. The curves are shown in Figures 1–3. Outcomes on achievement measures are in *z*-scores and are placed on the x-axis, while the y-axis represents the probability of a family history of disability. The probability, given a score on an achievement measure, can be roughly determined by visual inspection of the graph. Inspecting the example of reading comprehension in the FH DYS subgroup, as shown in the right-most panel of Figure 1, yields an approximate probability score of family history of dyslexia at 50% for a standard score of −2. Another way of determining a probability of a family history of dyslexia is to calculate the exact probability scor e based on beta weights in Table 4 with the following equation $1/(1+e^{-(\beta\ intercept + (\beta\ reading\ comprehension) * (standard\ score\ on\ reading\ comprehension))}$. Thus, if a

twin scored −2 SD on the reading comprehension, his/her probability of FH DYS+ would be $1/(1+e^{-(-1.163+(-0.535)*(-2))}) = 0.477$ *or* 47 . 7%. The same types of calculations can be applied to estimating probabilities for other subgroups and achievement measures.

Probability curves also show a marked difference in the relation between low achievement outcomes, in particular for reading comprehension and spelling, and the density of family history. As indicated in left-most and middle panels of Figures 1 and 2, the probability curves are flatter if twins only had one affected parent. In contrast, in right-most panels of Figures 1 and 2, a more exaggerated trend towards a sigmoidal shape of the curves is seen if either of the parents was affected. This suggests that a low performance on reading and spelling was a better indicator of FH+ status for twins with either of the parents being affected as opposed to twins with only one affected parent.

Turning to correlational analyses, twin ICCs are presented in Table 3 for all achievement measures. For the total sample, ICCs were consistently higher in MZs than in DZs for all measures, indicating the presence of some genetic influences on variation of these phenotypes. Further, the DZ ICCs were greater than half the MZ ICCs for all measures, indicating some shared environmental effects. Finally, MZ ICCs were less than 1, indicating non-shared environmental influences. Visual examination of ICCs by FH subgroups indicated likely no differential etiology across the FH subgroups. The ICCs estimates were very similar in magnitude in the FH+ and FH− subgroups. Table 3 also presents a summary of the univariate ACE model fitting results for each measure for each FH subgroup. For all three measures, the univariate ACE models for the FH subgroups showed some variability in the estimates of each parameter. However, given how close the estimates were between the subgroups, a multi-group analysis would most likely not show any group differences in etiology. In addition, the sample size of the twins in the FH+ subgroups was somewhat small and therefore the power to detect etiological differences between the FH+ and FH− subgroups was relatively low.

Indeed, the multi-group model fitting results across FH subgroups in Table 4 confirm these assumptions. The analyses showed that these differences were not significant as the fully constrained model, where A, C, and E estimates were set to be invariant, fit the data and could be selected over the fully unconstrained model for each achievement measure. Hence, the magnitudes of A, C, and E variance components for a particular achievement measure are equivalent across the FH subgroups.

Discussion

The role of family history has been highlighted as an important component in the evaluation of learning disabilities (Vogler et al., 1985). Thus, the goal of this report was to examine genetic and environmental influence on various achievement outcomes (reading, spelling, math) in two subgroups based on family history of learning disability, and assess the presence of possible etiological differences across the two subgroups. Prior literature provided evidence for both presence and absence of etiological differences.

We found significant small to moderate mean differences between children with a family history and children with no family history on reading and spelling outcomes, but not on math fluency. These reading and spelling results are in line with previous literature (for a review see Snowling & Melby-Lervåg, 2016), which shows that children with a family history underperform on achievement outcomes in comparison to children with no family history. With regard to math fluency, these results were not consistent with prior investigations (Fletcher et al., 2007) as significant mean differences would be expected also for this outcome. It is not known why there were no significant mean differences on the math fluency measure, versus the rest of the measures, but the consistency of the results of these other measures is compelling.

Given the fact that achievement outcomes are genetically and environmentally influenced, children with a positive family history are considered as at risk for falling on the lower tail end of the normal distribution of academic achievement performance. The risk, however, is not deterministic, but rather probabilistic, thus not all children with a positive family history will end up having difficulties in reading, spelling, and/or math (Snowling & Hulme, 2012). Our results indicated that performance on the achievement measures appears to be a noteworthy indicator of family history status. Specifically, the likelihood of a family history of disability increases when twins score low on reading, spelling, and math measures and vice versa, it decreases with higher scores on achievement outcomes. Such results are in line with previous research (e.g., Puolakanaho et al., 2007) and expected in the sense that if learning (dis)abilities are passed on via genetic and environmental routes, then we should predict there to be less of a likelihood of a family history of disability in high achieving versus low achieving twins.

Even though familial risk status appears to be related to academic performance, such that there were mean differences in achievement outcomes between the subgroups based on family history, this seemingly is not manifested by differential etiology. The uniformity of genetic and environmental estimates across family history status, however, needs to be interpreted with caution. It is quite possible that larger mean differences would have manifested in etiological differences because larger mean differences would indicate that the groups were more different. Nonetheless, it appears that results from the current sample can, in part, be predicted from the generalist genes hypothesis (Plomin & Kovas, 2005) and Pennington's multiple deficit model of disability (Pennington, 2006). Both theories support the framework that overlapping underlying quantitative pattern of genetic effects underlies both variation in learning abilities and disabilities. In addition, findings from previous research on assortative mating have shown that parents and children tend to resemble each other in reading (dis)ability due this mechanism (e.g., Wadsworth, Corley, Hewitt, Plomin, & DeFries, 2002).

In terms of environmental influences, we conducted post-hoc analyses to examine if there were mean differences in home literacy environment between our two subgroups (FH DYS+ and FH DYS−). One would have expected to see mean differences in home literacy environment to be tied to different magnitude effects for shared environment on individual differences across achievement outcomes. Even though there were significant mean differences in home literacy environment between the two subgroups (Cohen's d =0.31), in

that children with no family history were raised in a more supportive home literacy environment, no differential etiology in the environmental piece of the variance for achievement outcomes was incidental to those mean differences. This was unexpected because there is accumulating evidence from the gene by environment interaction literature that suggests that reading (dis)ability owes more to genetic influences (thus, less to environmental) in favorable environments (e.g., Kremen et al., 2005; Friend, DeFries, Olson, 2008). In addition, literature on gene environment correlation shows that the environments to which children are being exposed are partly determined by children's own genetic predispositions, whose effects are accentuated by the correlated environments. In fact, there is specific evidence that this kind of mechanism is operational in reading disability (e.g., Scarborough, Dobrich, & Hager, 1991). Nevertheless, it seems that for our sample family history status and the environment tied to it do not mirror in magnitude differences of environmental piece of the variance across the subgroups.

As with any study, there are limitations to the present study. First, the question to which extent the effect of family history of learning disability on achievement is generalizable across populations, and environments remains to be answered. Given the wide range of (home learning) environmental circumstances in which children around the world are raised, one would expect the effect to not necessarily occur in every population. Thus, it would be worthwhile to replicate the current findings with other datasets within and outside the United States. Another reason for replication is the sample size in our report. It is relatively small, resulting in broad confidence intervals for some parameter estimates (e.g., additive genetics) and potentially lower power to detect differences between models. However, parameter estimates from the constrained models were similar to the A, C, and E estimates from the fully unconstrained models suggesting that observed effects are not merely the results of constraining parameters. Second, with regard to the sensitivity of the family history measure, results need to be considered in the light of its limitations. Some parents might have not been certain about endorsing family history status in the questionnaire. Indeed, previous work has shown that when parents' assessment for reading disability is based on self-report, the familial incidence tends to be lower than when assessment is based on the direct measurement of parents' reading skills (Gilger, Pennington, & DeFries, 1991; Olson, 2000). Thus, our results utilizing the present family history measure should be considered as providing a certain trend regarding prediction of achievement outcomes and their etiological differences. Future studies should incorporate direct measures of parents' reading and math skills as more sensitive indicators of children's risk of developing learning disabilities.

All in all, the conclusion that there are no etiological differences in achievement outcomes based on family history status does not imply that family history does not make a difference. The fact that there are mean differences in achievement outcomes across the two subgroups still indicates that children with a family history underperform compared to their peers. Moreover, our results indicate that low performance on achievement outcomes is a salient indicator of positive family history status. Thus, children's progress in literacy and math development warrants close monitoring particularly for children with the family history risk. However, the data suggest that etiology of achievement outcomes is uniform across the family history status and that a family history per se does not seem to contribute to differential etiology of achievement outcomes in our sample.

Acknowledgments

This research was supported, in part, by a grant from the National Institute of Child Health and Human Development (P50 HD052120). Views expressed herein are those of the authors and have neither been reviewed nor approved by the granting agencies.

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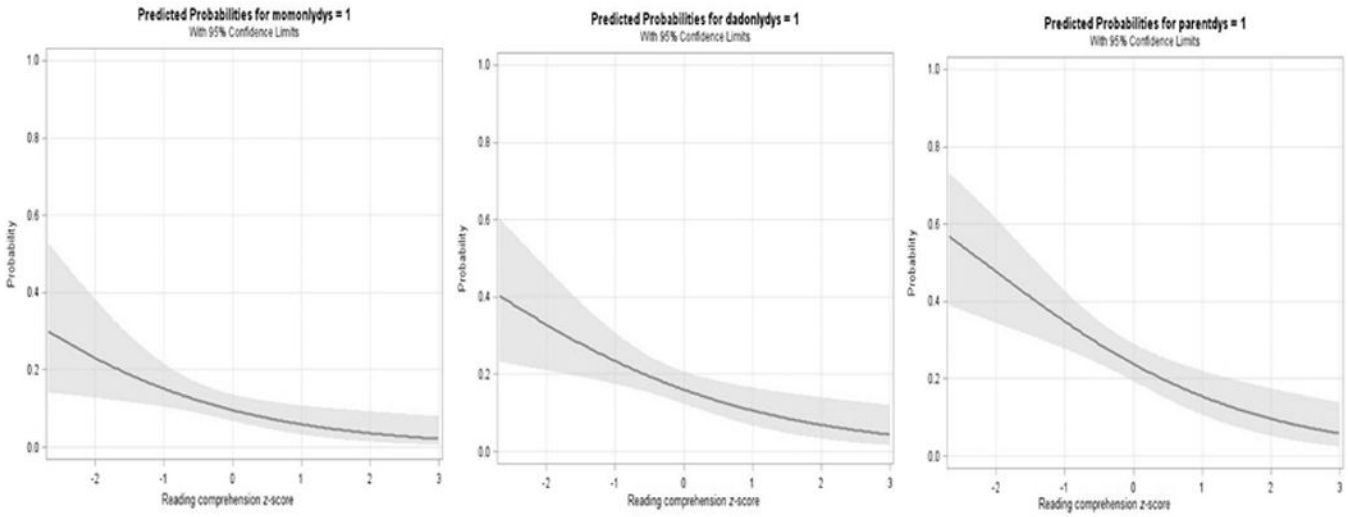

Figure 1:

Probability curves of a family history of dyslexia across the performance continuum (in standardized scores) on reading comprehension. The first two panels refer to twins with one affected parent (panel 1 – mother, panel 2 – father) reporting difficulties in reading, or spelling, or having dyslexia. The third panel refers to twins having either of the parents reporting difficulties in reading, or spelling, or having dyslexia. Shaded areas represent 95 % confidence intervals.

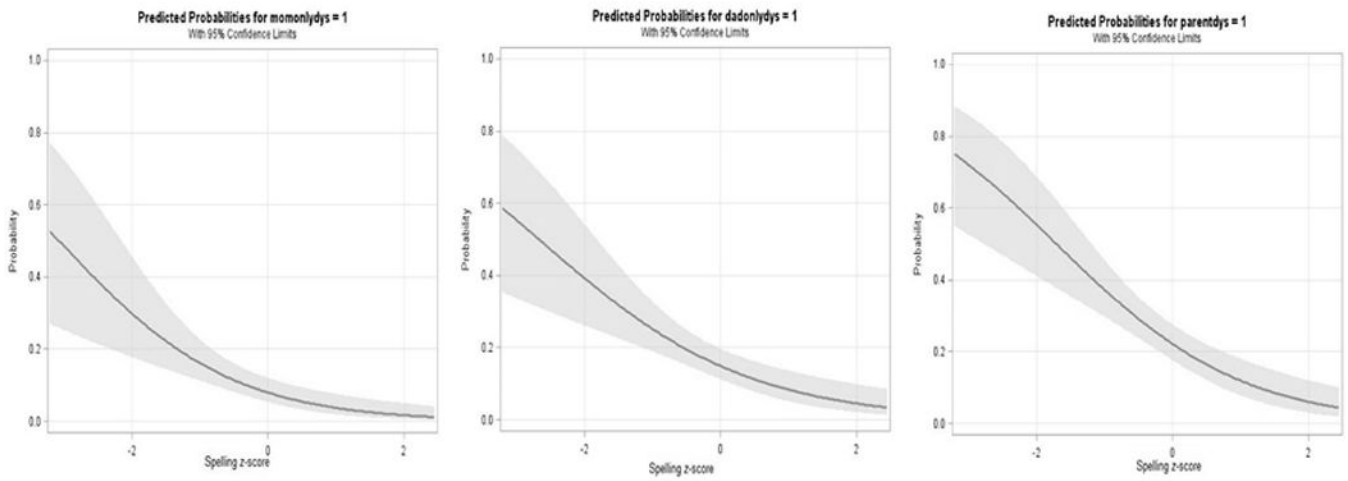

Figure 2:

Probability curves of a family history of dyslexia across the performance continuum (in standardized scores) on spelling. The first two panels refer to twins with one affected parent (panel 1 – mother, panel 2 – father) reporting difficulties in reading, or spelling, or having dyslexia. The third panel refers to twins having either of the parents reporting difficulties in reading, or spelling, or having dyslexia. Shaded areas represent 95 % confidence intervals.

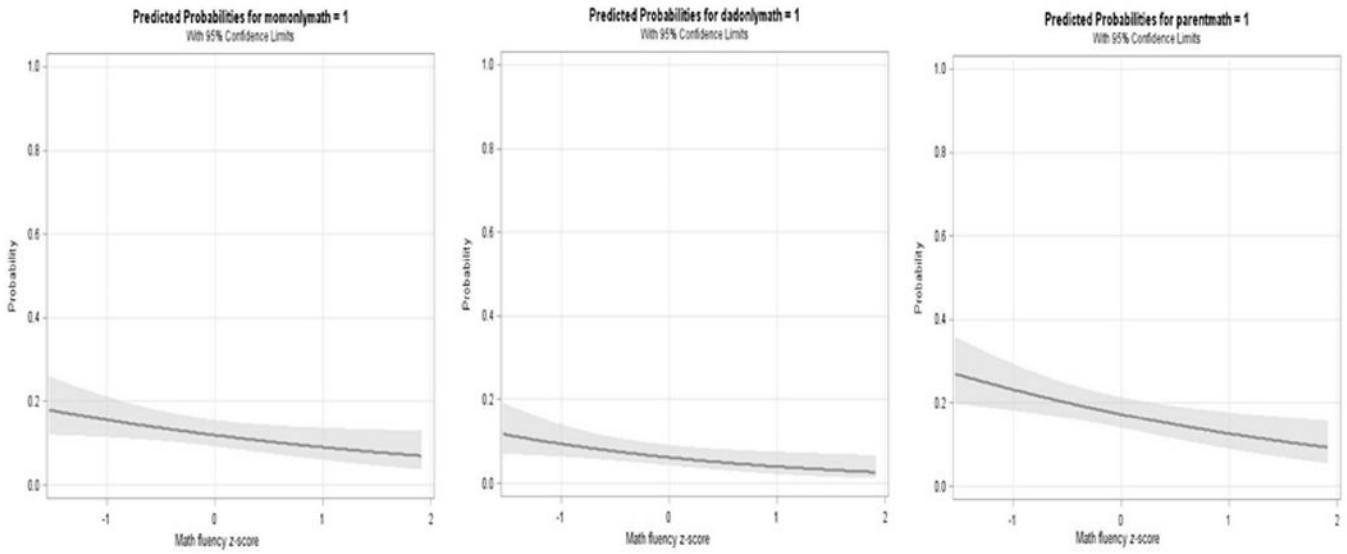

Figure 3:

Probability curves of a family history of math difficulties across the performance continuum (in standardized scores) on math fluency. The first two panels refer to twins with one affected parent (panel 1 – mother, panel 2 – father) reporting difficulties in math. The third panel refers to twins having either of the parents reporting difficulties in math. Shaded areas represent 95 % confidence intervals

Table 1.

Descriptive statistics, t-tests with Cohen's d effect sizes for all measures for the total sample as well as by FH subgroups

Achievement Outcome	FH Subgroup	Mean	SD	N	Skew	Min	Max	*t*-value (df)	*p*-value	Cohen's *d*
Reading	Total	104.79	14.46	634	0.27	66.00	148.00			
Comprehension	FH DYS+	102.73	13.65	158	0.48	78.00	142.00	2.08 (632)	.0381	0.19
	FH DYS−	105.48	14.66	476	0.20	66.00	148.00			
Spelling	Total	102.35	14.83	613	−0.06	54.00	138.00			
	FH DYS+	97.60	15.17	149	−0.23	54.00	138.00	4.56 (611)	<0.0001	0.42
	FH DYS−	103.88	14.41	464	0.04	62.00	138.00			
Math Fluency	Total	67.41	43.50	856	−0.33	0.00	150.00			
	FH MATH+	62.18	45.10	153	−0.20	0.00	144.00	1.64 (854)	.1008	0.14
	FH MATH−	68.55	43.10	703	−0.36	0.00	150.00			

Note. Total indicates twins with a family history and twins with no family history combined. The *t*-values result from comparing twins with a family history of a particular disability to twins with no family history of that disability. The *p*-value is the significance test for the *t*-test, and Cohen's *d* is the corresponding effect size. The sample size across FH subgroups reflects twins that had available data on a particular achievement measure. FH+ = twins with a family history of a particular learning disability, FH− = twins with no family history of a particular learning disability.

Table 2.

Logistic regression models

FH Subgroup (N)	Achievement Outcome	*β*	SE	*p*	Odds Ratio [CI]
FH MOM DYS+ (34) vs.	Intercept	−2.241	0.198	<.0001	0.596 [0.400–0.868]
FH MOM DYS− (289)	Reading comprehension	−0.518	0.196	.008	
FH DAD DYS+ (55) vs.	Intercept	−1.653	0.157	<.0001	0.625 [0.453–0.849]
FH DAD DYS− (268)	Reading comprehension	−0.469	0.160	.003	
FH DYS+ (81) vs.	Intercept	−1.163	0.136	<.0001	0.586 [0.440–0.768]
FH DYS− (242)	Reading comprehension	−0.535	0.142	.0002	
FH MOM DYS+ (31) vs.	Intercept	−2.244	0.227	<.0001	0.452 [0.301–0.662]
FH MOM DYS− (281)	Spelling	−0.795	0.199	<.0001	
FH DAD DYS+ (52) vs.	Intercept	−1.742	0.169	<.0001	0.521 [0.375–0.713]
FH DAD DYS− (260)	Spelling	−0.651	0.163	<.0001	
FH DYS+ (76) vs.	Intercept	−1.256	0.145	<.0001	0.480 [0.353–0.639]
FH DYS− (236)	Spelling	−0.734	0.151	<.0001	
FH MOM MATH+ (53) vs.	Intercept	−1.995	0.151	<.0001	0.734 [0.551–0.976]
FH MOM MATH− (376)	Math Fluency	−0.308	0.145	.0336	
FH DAD MATH+ (29) vs.	Intercept	−2.715	0.208	<.0001	0.634 [0.431–0.920]
FH DAD MATH− (400)	Math Fluency	−0.455	0.191	.0175	
FH MATH+ (77) vs.	Intercept	−1.563	0.130	<.0001	0.691 [0.539–0.883]
FH MATH− (352)	Math Fluency	−0.370	0.126	.0032	

Note. FH+ = twins with a family history of a particular learning disability, FH− = twins with no family history of a particular learning disability, N = only one twin from each pair was selected. Thus, N is the total number of twins from each separate pair of twins, *β* = beta weights, SE = standard error, *p* = significance value.

Table 3.

Twin intraclass correlations for achievement outcomes by zygosity for the whole sample (total) and by FH subgroup (FH+ and FH−), and summary of ACE standardized parameter estimates with 95% confidence intervals [CIs] by FH subgroup

Achievement Outcome	Total	FH+	FH−	FH+			FH−		
				A [CI]	C [CI]	E [CI]	A [CI]	C [CI]	E [CI]
Reading Comprehension									
MZ (N)	.63 (252)	.63 (69)	.62 (183)	**.42**	.30	**.28**	**.31**	**.33**	**.37**
DZ (N)	.49 (378)	.48 (89)	.48 (289)	**[.04−.83]**	[.00−.57]	**[.17−.49]**	**[.06−.65]**	**[.02−.58]**	**[.27−.50]**
Spelling									
MZ (N)	.57 (248)	.58 (66)	.54 (182)	.52	.09	**.39**	**.55**	.05	**.40**
DZ (N)	.34 (361)	.30 (83)	.32 (278)	[.00−.77]	[.00−.63]	**[.23−.65]**	**[.21−.71]**	[.00−.39]	**[.29−.55]**
Math Fluency									
MZ (N)	.87 (339)	.95 (60)	.86 (279)	**.37**	**.54**	**.09**	**.29**	**.60**	**.11**
DZ (N)	.66 (511)	.73 (93)	.64 (418)	**[.10−.65]**	**[.26−.78]**	**[.04−.16]**	**[.16−.43]**	**[.46−.71]**	**[.08−.15]**

Note. All correlations were significant at $p < 0.001$. Significant A, C, E estimates are bolded. Subgroups in columns 3−6 are as follows: Reading Comprehension: FH DYS+/FH DYS−, Spelling: FH DYS +/FH DYS−, Math Fluency: FH MATH+/FH MATH−. Parameter estimates are provided for the full ACE univariate models by family history status. FH+ = twins with a family history of a particular learning disability, FH− = twins with no family history of a particular learning disability, N = number of individuals, MZ = monozygotic twins, DZ = dizygotic twins, A = additive genetic influences, C = shared environmental influences, E = non-shared environmental influences.

Table 4.

Summary of multi-group model fitting for achievement outcomes across FH subgroups

Achievement Outcome	FH subgroup	Model	−2LL	*df*	AIC	Δx^2	Δ*df*	*p*	Additive Genetics – A [CI]	Shared Environment – C [CI]	Nonshared Environment – E [CI]
Reading	FH DYS+	U	1486.43	553	380.43	−	−	−			
Comprehension	vs. FH DYS−	C[a)]	**1487.71**	**556**	**375.71**	**1.29**	**3**	**.73**	**.38 [.10−.67]**	**.28 [.02−.49]**	**.34 [.26−.45]**
Spelling	FH DYS+	U	1466.38	532	402.38	−	−	−			
	vs. FH DYS−	**C**	**1468.47**	**535**	**398.47**	**2.10**	**3**	**.55**	**.57 [.22−.70]**	.04 [.00−.31]	**.39 [.30−.52]**
Math Fluency	FH MATH+	U	1451.10	627	197.10	−	−	−			
	vs. FH MATH−	**C**	**1455.89**	**630**	**195.89**	**4.79**	**3**	**.19**	**.34 [.22−.48]**	**.55 [.42−.66]**	**.11 [.08−.14]**

Note. −2LL= negative 2 log likelihood, U = unconstrained, C = constrained, − = N/A, FH+ = twins with a family history of a particular learning disability, FH− = twins with no family history of a particular learning disability. The best fitting models and significant A, C, E estimates are bolded. Analyses were conducted on standardized data, controlling for age, age squared, and sex.

*a)*Constrained models are models with variance components (A, C, E) constrained. Results from model fitting with constrained means and variances can be obtained from the first author upon request. In short, similar results in terms of magnitudes of genetic and environmental influences on academic achievement outcomes emerged from that model fitting.