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Examining the genetic and environmental associations among spelling, reading fluency, reading comprehension and a high stakes reading test in a combined sample of third and fourth grade students

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Abstract

The present study is an examination of the genetic and environmental effects on the associations among reading fluency, spelling and earlier reading comprehension on a later reading comprehension outcome (FCAT) in a combined sample of 3rd and 4th grade students using data from the 2011-2012 school year of the Florida Twin project on Reading (Taylor et al., 2013). A genetically sensitive model was applied to the data with results indicating a common genetic component among all four measures, along with shared and non-shared environmental influences common between reading fluency, spelling and FCAT.

Reading comprehension skills are associated with academic success in both primary and secondary education (Slavin, Madden, Karweit, Livermon, & Dolan, 1989). Education and academic success are subsequently linked with overall health and well-being in the United States, with disparities in one contributing to disparities in another (Fiscella & Kitzman, 2009). In recognition of the important relationship among reading, academic success and health the government passed the No Child Left Behind Act (NCLB) in 2001, (Act, 2002) which seeks to improve education through standardized assessments and culpability for teachers, schools and districts when target reading levels are not met. More recently, the Common Core of State Standards Initiative is being introduced to incorporate a single set of educational standards, with the intention of all states moving towards adopting a single annual assessment of the Common Core standards. For both the NCLB Act and Common Core, reading comprehension is a key skill required for success.

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Reading fluency is defined as the oral translation of text with speed and accuracy and has been identified as one of the components of reading critical to building a bridge to reading comprehension (Adams, 1990; Fuchs, Fuchs, Hosp, & Jenkins, 2001; Pikulski & Chard, 2005). Automatic and accurate word recognition is theorized to reduce the cognitive load involved with lower-level word processing during reading, which allows a greater availability of resources to the performance of higher-level comprehension functions involved with skilled reading comprehension (LaBerge & Samuels, 1974). In addition to automaticity, reading fluency involves prosody. Prosodic reading involves grouping words together into meaningful sections that follow with the syntactic structure of the text and has been theorized to be a link between automaticity and reading comprehension (Kuhn & Stahl, 2003). Fluent readers are able to quickly and accurately decode as well as successfully transfer syntactic knowledge from speech to text during silent reading. A review suggested a moderate to high association between reading fluency and reading comprehension, with correlations of .50 to .90 (Fuchs et al., 2001). Additionally, in a study of the predictive ability of fluency on reading comprehension, results showed the relation between fluency and reading comprehension improved positively as participants' fluency skills increased (Petscher & Kim, 2011). Reading fluency has also been associated with success on high stakes, state-wide reading assessments (Baker et al., 2008).

In addition to fluency skills, spelling has been identified as a skill significantly related to success in reading comprehension (Ehri, 2000; Hook & Jones, 2002; Nunes, Bryant, & Barros, 2012; Pikulski & Chard, 2005;). Spelling can be defined as the interactive process of mapping phonological (sound) representations of words onto their orthographic (written) counterparts (Hanna, 1965). Importantly, the ability to derive corresponding orthographic units from phonemic units and vice-versa plays an important role in word -decoding, reading and writing. Ehri and colleagues (e.g. Bhattacharya & Ehri, 2004; Drake & Ehri, 1984) have been able to illustrate the importance of phoneme-grapheme correspondence used in spelling and decoding to gains in reading fluency, but recognize that exposure through reading may also have a positive impact on spelling. Furthermore, the use and understanding of graphophonic units (units smaller than morphemes) that comprises spelling ability has been found to benefit morphological awareness and contribute to increased word reading fluency and reading comprehension (Nunes et al., 2012). A moderate and positive relation between spelling and reading comprehension has been indicated in languages with transparent orthography such as Finnish, Dutch and Greek (Mommers, 1986; Protopapas, Sideridis, Mouzaki, & Simos, 2011; Savolainen, Ahonen, Aro, Tolvanen, & Holopainen, 2008). The relation in English speakers is less-studied, although the work that is done also suggests a positive association, r = .68-.89 (Ehri, 2000; Foorman & Petscher, 2010). In addition, results of a longitudinal study showed spelling ability in a sample of first grade students significantly predicted reading comprehension in fifth grade (Roberts & Meiring, 2006). This growing body of work indicating a close association between spelling ability and reading comprehension has led to an increased focus on spelling as a part of reading instruction (Foorman & Petscher, 2010), though the underlying nature of spelling is often considered separate from reading comprehension (Aarnoutse, Van Leeuwe, Voeten, & Oud, 2001).

The Lexical Quality Hypothesis of reading comprehension classifies components of language processing as having an influence on accuracy and fluency of word identification through their contributions to the lexical quality of the word (Perfetti, 2007; Perfetti & Hart, 2001). Under this hypothesis, aspects of orthography and phonology influence the lexical quality of words within text and, in combination with semantic knowledge, account for much of the variance in text comprehension. The Lexical Quality Hypothesis suggests that variations in orthographic (spelling) and phonological decoding contribute to variations among word reading and comprehension skills, therefore, spelling is considered a key predictor of reading comprehension, outside of the more commonly studied phonological decoding predictors. More recently, reading fluency, spelling and reading comprehension have been examined together (Foorman & Petscher, 2010; Foorman, Petscher, & Bishop, 2012; Nunes et al., 2012). One study explored the role of reading fluency and reading comprehension on spelling, with the results indicating that reading fluency accounted for more variance in spelling than did reading comprehension (Foorman & Petscher, 2010). In addition, high ability spellers outperformed low ability spellers on both fluency and reading comprehension (Foorman & Petscher, 2010). Additionally, spelling ability has been identified as an independent predictor of reading comprehension, above and beyond both morphological awareness and reading fluency (Nunes et al., 2012). In another recent examination, a model with reading fluency, spelling, prior reading comprehension, and morphology explained nearly all of the between classroom variance in reading comprehension skills, indicating that spelling and reading fluency are both important predictors of reading comprehension ability for students in grades 3-10 (Foorman et al., 2012). While there is considerable literature on the nature of spelling and reading comprehension or fluency and reading comprehension skills, more research on the relations between reading fluency, spelling and reading comprehension is needed to learn how these three skills interplay and, ultimately, how reading comprehension skills develop.

Quantitative genetic methodology allows the unique opportunity to examine the genetic and environmental components underlying the relations among achievement measures. Specifically, twin study methodologies compare the known genetic and environmental similarity between monozygotic and dizygotic twins to examine the proportion of variance attributable to additive genetic influences (or heritability; h^2), shared environmental influences (i.e., non-genetic influences that make siblings more similar; c^2), and non-shared environmental influences (i.e., non-genetic effects that make siblings different, plus error; e^2) on a given measure. Previous twin work has found moderate to high heritability estimates for comprehension (h^2=.32-.82)[1], fluency (h^2=.29-.49) and spelling (h^2=.54 and .51; Bates et al., 2007; Byrne et al., 2008; Hart, Petrill, & Thompson, 2010; Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006; Logan et al., 2013; Petrill et al., 2011). Shared environmental influences on fluency are mostly non-significant and non-shared environmental estimates are significant, but smaller than additive genetic effects (.29-.39; Hart, Petrill, Thompson, & Plomin, 2009; Petrill et al., 2012). However, in one study examining a younger sample of twins in the pre-reading stage, results indicated low to

[1]The wide range of heritability estimates included may, in part, be due to different age ranges (early childhood through adolescence) or different demographic characteristics (i.e. race, nationality) of the included samples.

moderate and significant estimates of shared environmental influence on fluency (c^2=.10-.36; Taylor & Schatschneider, 2010). Studies of spelling ability have generally shown non-significant shared environmental effects (c^2=.00-.19) while estimates of non-shared environmental influence have been found to be significant, but varied (e^2=.49 and .23; Bates et al., 2007; Byrne et al., 2008). Univariate analysis of reading comprehension reveals a pattern of influence similar to fluency and spelling with non-significant estimates of shared environmental influence, and significant non-shared environmental influence (.30-.54; Hart, Soden, Johnson, Schatschneider, & Taylor, 2013; Keenan et al., 2006; Logan et al., 2013).

Importantly, multivariate genetic methods can also examine genetic and environmental influences on the covariance among reading fluency, spelling, and reading comprehension. Previous work examining the genetic and environmental influences shared between reading fluency and reading comprehension has shown evidence of a significant common genetic influence between these two skills as well as significant independent genetic influences on fluency, but not reading comprehension (Hart et al., 2010; Petrill et al., 2012). Shared environmental effects were significant between reading fluency and reading comprehension, but not significant for independent shared environmental influences for either (Hart et al., 2010; Petrill et al., 2012). However, no multivariate work has explored the genetic and environmental association of the relation between spelling and reading comprehension or among all three skills simultaneously.

Florida mirrors the national movement in the U.S. towards universal end-of-year assessments of educational standards. Annual student performance in reading, particularly focused on reading comprehension skills, is assessed by the Florida Comprehensive Assessment Test 2.0 (FCAT; http://fldoe.org). Due to the importance of passing the end-of-year, high-stakes FCAT for both students and teachers, the state has also developed the Florida Assessment for Instruction in Reading (FAIR). The FAIR is designed to act as a predictor of success on the FCAT. Importantly, the FAIR measures specific component reading skills hypothesized to be predictive of reading comprehension measured by the FCAT, namely reading fluency, spelling and a separate test of reading comprehension. Scores from FAIR Maze Task (reading fluency), Word Analysis (spelling), and Reading Comprehension are used to estimate the probability of a student passing the reading comprehension portion of the FCAT at the end of the same school year (Foorman & Petscher, 2009). As the U.S. moves towards the Common Core standards (CCSS), there will be increased pressure for more interim assessments intended to predict success on the important end-of-year tests and provide a rubric for mid-year intervention efforts. Importantly, even with the growing body of literature on the relationship between reading fluency, spelling and reading comprehension and its important role in assessing student achievement, the nature of these relations is still not well understood. Understanding the nature of this association is salient in understanding how to prepare students for the standardized assessments called for in response to No Child Left Behind (NCLB, 2002) and more recently the Common Core. Additionally, these assessments were chosen in order to capture the breadth of comprehension, fluency, and decoding skills. Most word-level reading fluency measures capture automaticity (swift decoding), but not prosody, which is also an important contributor to sentence and passage level comprehension (Kuhn & Stahl, 2003; Pikulski & Chard, 2005). Maze fluency tasks are typically used to measure silent

reading fluency which captures both automaticity and prosody (Jenkins & Jewell, 1993). The FAIR subtests measure aspects of decoding through both the spelling and fluency subtests, while also measuring aspects of prosodic fluency through the timed presentation of passage-level text. Using these measures allows for a comprehensive measurement of reading comprehension and its component skills. Finally, these measures are similar to other accepted curriculum-based and norm-referenced measures such as the *Woodcock-Johnson III* Spelling subtest, the Basic Academic Skill Samples Reading test (BASS Reading), and the Gates-McGinitie Comprehension subtest (Deno, Maruyama, Espin, & Cohen, 1990; MacGinitie, 2000; Woodcock, McGraw, & Mather, 2001, 2007), which allows for the generalization of the underlying nature of the relations between the FAIR and FCAT reading variables to other measures of reading comprehension and its subcomponent skills.

The primary aim of this study is to add to the literature examining the relation of reading fluency and spelling to reading comprehension. Specifically, this is the first study we know of to examine the genetic and environmental influences on the shared covariance among the component literacy skills of reading fluency, spelling and reading comprehension, as well as the genetic and environmental influences on each skill not accounted for by the shared effects. This will allow for a better understanding of the nature of the relation of reading fluency and spelling to reading comprehension, highlighting the etiology of the associations commonly measured in non-genetically sensitive samples. To do this, we examined the reading fluency, spelling and reading comprehension subtests of the FAIR and the FCAT reading assessment using a combined sample of third and fourth grade students using data from the 2011-2012 school year of the Florida Twin Project on Reading (Taylor, Hart, Mikolajewski, & Schatschneider, 2013). Third and fourth grades are especially important to focus on as these two school years are commonly considered key years for reading comprehension development. Additionally, given that the nature of the FAIR testing is for progress monitoring and prediction of success on the FCAT, these analyses will focus on the fall testing of FAIR, with FCAT testing the following spring. Similar to other progress monitoring assessments, results from the fall testing of FAIR are used to make decisions on individualizing instruction and possible intervention plans to facilitate success on the FCAT, so we were particularly interested in the relations between these two time points.

In total this study will explore any overlap of genetic and environmental influences between reading fluency, spelling and reading comprehension as measured by FAIR and FCAT. Understanding the relations between these skills is essential in understanding the role of reading fluency and spelling on reading comprehension. More broadly, understanding these relations will also allow for a better insight as to the role of progress monitoring assessments in preparing students for high-stakes end-of-year assessments.

Methods

Participants

The Florida Twin Project on Reading is a cohort-sequential project of twins in Florida (Taylor & Schatschneider, 2009; Taylor et al., 2013). Progress monitoring and achievement data on reading for the twins is collected via Florida's Progress Monitoring and Reporting Network (PMRN), a statewide educational database. For the present study, Florida

Assessment for Instruction in Reading (FAIR) and Florida Comprehensive Assessment Test Reading (FCAT 2.0) scores from the 2011-2012 school year were obtained from the PMRN database. These assessments are administered by trained individuals within the schools and then uploaded into the PMRN database. Twins who were identified has being in different grades from each other where excluded from the analyses. Reading scores from FAIR and FCAT 2.0 were obtained for 596 twin pairs in 3rd grade (217 monozygotic, 191 opposite-sex dizygotic, 188 same-sex dizygotic) and 508 twin pairs in 4th grade (158 monozygotic, 165 opposite-sex dizygotic, 185 same-sex dizygotic). Twins were approximately 9 years old in third grade (M=8.78, SD=.53) and 10 years old in fourth grade (M=9.93, SD=.63). The third and fourth grade data were combined together in order to create a large sample of 1104 pairs of twins. Of this combined sample, 51.2% were Caucasian, 23.9% Hispanic, 16.1% African American, 6.2% Mixed Race and 2.7% Asian, Native American/Pacific Islander or Other. The sample was 48% female and the percentage of twins that qualified for Free or Reduced Lunch Status was 58.5%. English was spoken in all classrooms and testing was conducted in English.

Measures

Zygosity for the twin pairs was determined via a parental five-item questionnaire on physical similarity obtained during intake of the twin families into the project (Lykken, Bouchard, McGue, & Tellegen, 1990). Trained testers administered progress monitoring measures as part of normal school attendance and all scores were entered into the PMRN web-based data collection system. FAIR in 3rd through 10th grades is a computer adaptive assessment of reading performance including subtests of reading comprehension, spelling ability (Word Analysis) and reading fluency (Maze Task) given at three assessment periods within a school year. The formal testing procedure for the FAIR indicates that the subtest of reading comprehension acts as a screener for potential failure on the FCAT, with those children below an 85% chance of passing the FCAT (based on an algorithm determined by the test makers) then administered the Word Analysis and Maze subtests. Children with a high chance of passing stop after the reading comprehension subtest. However, individual schools may choose to administer all FAIR subtests to all children, and in practice almost all schools in Florida are doing so. In these data, 94.7% of the sample who took the reading comprehension subtest also took the Word Analysis subtest, and 96.2% took the Maze subtest. During the 2011-12 school year, the fall testing of FAIR was administered within a 45 day window beginning in August and ending in October.

The FCAT is administered once per school year in grades 3 through 10 and measures several areas of student achievement covered by Florida Sunshine State Standards. Scheduled administration of the FAIR and FCAT was determined by the Florida Department of Education and local school districts. For the present study, grade-standardized scores from the first administration of the FAIR for grades 3 and 4 were analyzed. During the 2011-12 school year, FCAT testing occurred in the 3rd week of April.

Reading Comprehension—The Reading Comprehension subtest of the FAIR is a computer-administered assessment used to determine the probability of student success on the reading subtest of the FCAT. Students read through one to three narrative or expository

passages and then answer seven to nine multiple choice questions about the passages. The number of passages and multiple choice questions supplied is adaptive and dependent on student performance. The responses are analyzed to give estimates of potential performance on the FCAT reading test. The generic estimate of reliability from item-response theory (IRT) for 3rd grade students is .88 and is .90 for 4th grade students (http://www.fcrr.org/fair/Technical%20manual%20-%203-12-FINAL_2012.pdf).

Fluency—The FAIR fluency, or Maze Task, assesses fluency skills involved in text reading efficiency. Students read passages and respond to questions presented via computer. Students read two passages in three minutes and are scored on the number of correct responses to cloze items embedded within the passage. Generic reliability scores from IRT are estimated at .82 for 3rd grade students and .88 for 4th grade students (http://www.fcrr.org/fair/Technical%20manual%20-%203-12-FINAL_2012.pdf). Construct validity for this fluency measure was established by examining the correlations between responses to the FAIR fluency task and the Florida Oral Reading Fluency scores in grades 6-10. Correlations ranged from .51-.64 (Foorman et al., 2012). Additionally, construct validity of maze fluency measures was identified through a review that determined maze tasks were superior to word reading tasks in measuring change in reading fluency skills over time (Wayman, Wallace, Wiley, Tichá, & Espin, 2007). Additionally, within this review, one study examined the variability of correlations for reading aloud fluency tasks versus maze fluency tasks across grades and found the correlations for maze fluency tasks remained more consistent over time (Jenkins & Jewell, 1993).

Spelling—The spelling subtest of FAIR is called the Word Analysis Task and measures students' orthographic knowledge via a computer-adapted test that administers 5-30 items (i.e., words) depending on students' ability. Students listen to words through the computer speakers or headphones (no additional information is provided to assist students with the meanings of the words), and respond by typing the combination of letters believed to spell the word correctly. Spelling reliability estimates from item response theory are .93 for 3rd grade students and .92 for 4th grade students (http://www.fcrr.org/fair/Technical%20manual%20-%203-12-FINAL_2012.pdf).

FCAT—The Florida Comprehensive Assessment Test (FCAT) consists of criterion-referenced assessments in mathematics, reading, science, and writing, which measure student progress toward meeting the Sunshine State Standards (SSS) benchmarks (FLDOE, 2001). The reading portion of the FCAT consists of several narrative and expository passages for students to read, followed by multiple choice comprehension questions. FCAT 2.0 standard scores range from 140-302 with a passing score falling within the Level 3 range (189-209 in 3rd grade and 208-220 in 4th grade). Reliability for FCAT Reading Comprehension from IRT is .90 in 3rd grade (Foorman & Petscher 2010).

Results

Table 1 presents descriptive statistics for the FAIR and FCAT Reading Comprehension measures. Phenotypic (Pearson) correlations between all measures are listed in Table 2. Pearson correlations among all three of the FAIR assessments indicated moderate to large

and significant correlations (r = .42-.54) as well as each indicated large and significant correlations with FCAT (r = .48-.66).

Intraclass correlations

Twin intraclass correlations by zygosity were analyzed to provide an initial descriptive estimate of additive (or heritability; h^2), shared environmental (environmental influences which make family members more similar; c^2) and non-shared environmental (environmental influences which make siblings less similar, plus error; e^2) influences on each measure of reading performance (see Table 3).

Additive genetic effects were implicated because monozygotic twin (MZ) correlations (r_{MZ} = .54-.79) were higher in all instances than dizygotic twin (DZ) correlations (r_{DZ} = .24-.50). However, with reading comprehension the MZ correlations (.54) were closer in magnitude to the DZ correlations (.40) suggesting less genetic influence and greater shared environmental influences were present. In addition, the results suggested shared environmental effects because the MZ correlations were less than twice the DZ correlations for all variables, except for spelling. Correlations between MZ twins were greater than twice those for DZ twins for spelling, indicating potential dominance (nonadditive) genetic effects. The intraclass correlations also suggested non-shared environmental effects (and error) as indicated by MZ correlations less than unity (Neale & Cardon, 1992).

Univariate Analysis

As age and gender differences were not a focus of the current analyses, and these effects can bias twin analyses, the raw data were corrected for by residualizing on age, age-squared and gender, prior to analyses (McGue & Bouchard, 1984). In addition, given the participants could be in third or fourth grade, the raw data were residualized on total months of schooling to account for any effects of school experience that may inflate shared environmental estimates. All subsequent quantitative modeling was evaluated in Mx on all available raw data, using 95% confidence intervals to test for significance of parameter estimates (Neale, Boker, Xie, & Maes, 2006; Boker et al., 2011). Table 4 displays the results from univariate structural equation model fitting of the data for each measure.

As was implied by the intraclass correlations above, the results indicated significant genetic influences for reading fluency (h^2=.65), reading comprehension (h^2=.28), and FCAT (h^2=.52) in grades 3 and 4. Significant shared environmental influences were indicated for reading comprehension (c^2=.26) and FCAT (c^2=.27). All measures across both grades indicated significant non-shared environmental influences (including error; e^2=.21-.46). The estimate of non-shared environmental influence on reading comprehension was unusually large, but this was most likely due to a larger amount of measurement error with this assessment. To further explore the potential nonadditivity for spelling suggested by intraclass correlations and because both shared environment and dominance influences are confounded when only twins are used within a single model, separate univarate ACE and ADE models were compared for spelling. The ADE model resulted in lower Akaike Information Criterion (AIC; 703.839) and Bayesian Information Criteria (BIC; −1759.650) fit indices relative to the ACE model (AIC = 708.413; BIC = −1757.363) suggesting better

fit, though not considerably. Akaike's Information Criterion (AIC) and BIC are both modified versions of χ^2 (taking into account model complexity) thus with both AIC and BIC indices, lower values indicate a better fitting model (Hu & Bentler, 1999). Guidelines for considering the best model based on ΔAIC indicate that a ΔAIC ≤ 2 provides substantial support for the fit of the original model, ΔAIC between 4 and 7 provides considerably less support and ΔAIC >10 provides essentially no support for the original model (Burnham & Anderson, 2004). The ΔAIC between the ACE and ADE model is less than 7 (ΔAIC = 4.57), indicating some support for both the original and alternate models. Because neither the ACE nor ADE model clearly fit the data better than the other, estimates from both models are reported. Within the ACE model, additive genetic influences (h^2=.71) and non-shared environmental influences (e^2=.30), were significant. Additive (h^2=.21) genetic influences were non-significant within the ADE model, and dominance (d^2=.43) and non-shared environmental influences were significant (including error; e^2=.28).

Multivariate Analysis

Structural equation modeling was then used to examine the genetic and environmental contributions to the variance and covariance among reading fluency, spelling, reading comprehension and FCAT. Although intraclass correlations suggested dominance effects for spelling, they were not indicated for reading fluency, reading comprehension or FCAT. Since both shared environment and dominance influences are confounded when only twins are used within a single model and dominance was indicated for spelling only (with an ACE model providing model fit statistics equally adequate to the ADE model), an ACE model was selected for multivariate analyses. Therefore, a multivariate ACE Cholesky model was used on the combined third and fourth grade sample, to decompose the variance and covariance among the measures into biometric factors representing genetic (A), shared environmental (C) and non-shared environmental (plus error; E) influences. Specifically, the first set of biometric factors estimated represented the overlap of genetic and environmental influences on the covariance among reading fluency, spelling, reading comprehension and FCAT (represented by A_1, C_1, and E_1 in Figure 1). The second set of biometric factors (A_2, C_2, and E_2) corresponded to the overlap of genetic and environmental influences among spelling, reading comprehension and FCAT. The third set of biometric factors (A_3, C_3, and E_3) represented the genetic and environmental overlap on reading comprehension and FCAT, and the fourth set of biometric factors represented unique genetic and environmental influences specific to FCAT (A_4, C_4, and E_4). The Cholesky model was chosen as it allowed the relations in the data to be described as a single set of genetic and environmental influences underlying all four reading and spelling measures, as well as identifying genetic and environmental influences that may be unique to the measures. Additionally, we chose to model the variables in a way that allowed the relations to be explained as the component skills of reading fluency and spelling followed by the reading comprehension measures.

Table 5 presents the standardized path estimates of the multivariate Cholesky analyses (represented by Figure 1).

Results from the first set of biometric factors (A_1, C_1 and E_1) indicated a significant overlap of genetic influence across reading fluency (path estimate of .78), spelling (estimate of .45),

reading comprehension (path estimate of .46) and FCAT (path estimate of .48). Shared environmental influences were significant across all measures (c^2=.25-.48). Significant overlap of non-shared environmental influences was indicated for reading fluency (estimate of .48), spelling (estimate of .14) and FCAT (estimate of .14), but this overlap did not include reading comprehension (estimate of .01).

The second set of biometric factors (A_2, C_2 and E_2) indicated significant genetic influences on spelling (estimate of .65), overlapping with FCAT (estimate of .15). Shared environmental estimates were not significant. Non-shared environmental influences were significant for spelling (estimate of .55), but these influences did not significantly overlap between reading comprehension (estimate of .08) and FCAT (estimate of .06).

Looking at the third set of genetic and environmental influences (A_3, C_3 and E_3), results indicated genetic and shared environmental influences were non-significant. However, significant overlap of non-shared environmental influences was indicated for reading comprehension (estimate of .68) and FCAT (estimate of .12).

Lastly, the fourth set of biometric factors (A_4, C_4 and E_4) indicated no significant genetic (estimate of .00) or shared environmental (estimate of .00) influences on FCAT after accounting for any overlap with the previous factors. Non-shared environmental influences on FCAT alone were significant (estimate of .42). Model fit statistics indicated the multivariate model fit the data as suggested by the values for −2LL, Akaike's Information Criterion (AIC) and Bayesian Information Criterion (−2LL=9403.976; AIC= 1479.976; BIC= −7743.182).

Discussion

The main purpose of the current study was to investigate the influence of genetic and environmental factors on the relations among FAIR measures of reading fluency, spelling and reading comprehension on a later high stakes state standardized assessment of reading comprehension. Univariate results for reading fluency suggest significant large genetic and also non-shared environmental influences, a finding supported by previous work examining speeded measures of reading (i.e., Petrill et al., 2012). Previous research has reported additive genetic and shared environmental influences for spelling (Bates et al., 2007). The present findings from the ACE model of spelling support this previous work. Finally, the present study had two reading comprehension measures, one from the Florida progress monitoring test, FAIR, and the second representing the Florida high stakes end of year test, the FCAT Reading test. The FAIR reading comprehension measure, meant to be a predictor of success on the FCAT, indicated significant genetic, shared environmental influences and non-shared environmental influences (which include error). This is the first time this measure has been explored in a quantitative genetics framework, and the high e^2 estimate, unusual for standardized achievement outcomes, would suggest measurement error, although the source of this greater level of measurement error is unknown. The second reading comprehension outcome, the FCAT, indicated moderate and significant heritability and shared environmental influences, in line with recent work, (e.g., Christopher et al., 2013; Logan et al., 2013).

The results of the multivariate model suggested in part a generalist genetic overlap among the measures (e.g., Plomin & Kovas, 2005); additionally, shared genetic influences were found for spelling and FCAT after accounting for genetic overlap between reading fluency, spelling, reading comprehension and FCAT. The shared genetic component could be indicative of genetic influences on an underlying skill such as general cognitive ability or working memory that influences reading fluency, spelling and reading comprehension or it could also represent genes shared between these skills (Alarcon & DeFries, 1997; Hart, Petrill, & Thompson, 2010). These results support evidence from previous research indicating reading fluency and reading comprehension are highly inter-related skills (Fuchs et al., 2001). Above the first genetic factor, the second genetic factor indicated genetic influences overlapping between spelling and FCAT. Spelling is often considered a separate, although closely related, domain from reading (Aarnoutse, Van Leeuwe, Voeten, & Oud, 2001), though these results suggest spelling also shares etiological factors with reading fluency and reading comprehension. The finding of overlapping genetic influences for between spelling, fluency and reading comprehension supports the Lexical Quality Hypothesis, which posits that spelling and fluency are both important predictors of reading comprehension (Landi, 2010; Perfetti, 2007; Perfetti & Hart, 2001). However, more investigation of these skills is necessary to further understand the nature of their distinctions.

Turning towards the shared and non-shared environmental results from the multivariate model, the significant overlap of shared environmental influences between all of the factors along with the significant overlap of non-shared environmental influences between reading fluency, spelling, and FCAT suggests that shared and child-specific environmental factors are influencing both reading comprehension and its component skills. Significant non-shared environmental influences are indicated for spelling, but they do not overlap with reading comprehension or FCAT. Results also indicated significant non-shared environmental overlap between reading comprehension and FCAT, and on FCAT alone. It is important to note that the non-shared environmental influences in the present study may be almost entirely error and the true sources of these influences are unknown.

As with any work, there are limitations to the current study. The Florida Twin Project on Reading is large and diverse, but is limited in what achievement measures are chosen by the Florida Department of Education to be administered and, subsequently available in the PMRN database. Previous research in reading comprehension has pointed to other skills which are important for performance (such as word-level reading, language comprehension, etc.) which are not available. Related, the second limitation of this work is specific to the higher than typical univariate non-shared environmental estimates, especially for the FAIR reading comprehension measure. As the e^2 estimate includes error, these high estimates indicate the potential for increased measurement error. Potential common measurement error (given these measures are from the same test) may underlie the non-shared environmental overlap found between many of the present measures, and this should be taken into account when considering these findings.

The associations between reading fluency and spelling and their predictive relation with reading comprehension is important to the overall understanding of the nature of reading comprehension. Also, standardized testing has become a large component of children's

academic environments and, in the state of Florida, can determine promotion to the next grade level. As more school districts adopt Common Core State Standards and standardized assessments, knowing more about how success on these high-stakes assessments is influenced by genetic and child-level factors can inform assessment preparation practices of both teachers and parents. Additionally, knowledge of how these influences overlap with progress monitoring assessments can further inform the adoption of CCSS and accompanying end-of-year, high-stakes assessments across the U.S. While helping to broaden our understanding of the associations between these skills and how they are measured, future research is required to tease out the nuances demonstrated within these findings. With extended exploration of these results more can be learned about the influences that impact reading comprehension and its associated skills as well as the accurate measurement of these skills in standardized testing.

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Highlights

- Our study extends investigations of the relations between reading fluency, spelling and reading comprehension skills
- This investigation is the first to examine the genetic and environmental influences on reading fluency, spelling and reading comprehension
- Our investigation explores the underlying etiology of state standardized assessments aligned with the Common Core initiative
- Our study includes a large and diverse sample of twins

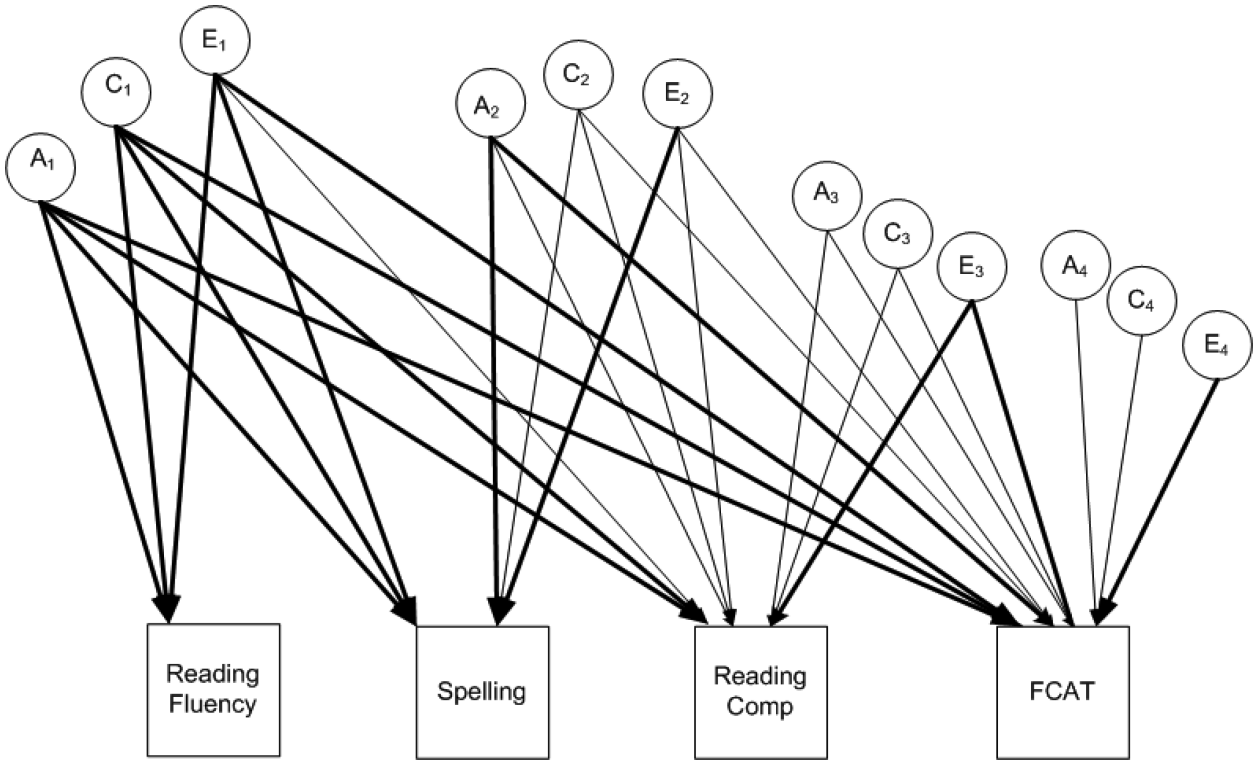

Figure 1.

Cholesky Model for combined 3rd and 4th grade FAIR and FCAT scores. Bolded pathways indicate significance based on 95% confidence intervals. Reading Comp = Reading Comprehension.

Table 1

Means, standard deviations (SD), minimums, maximums and skewness for combined 3rd and 4th grade FAIR and FCAT scores.

Variable	Mean	SD	Minimum	Maximum	Skew	*n*
Reading Fluency[a]	96.42	13.81	62.00	143.00	.17	1034
Spelling[a]	97.09	14.26	60.00	130.00	−.67	1018
Reading Comprehension[a]	96.43	11.31	68.00	145.00	.94	1075
FCAT	208.52	22.06	140.00	269.00	−.12	971

Note. n = number of individuals

[a]FAIR

Table 2

Phenotypic correlations for combined 3rd and 4th grade FAIR and FCAT scores.

Variable	Reading Fluency[a]	Spelling[b]	Reading Comprehension[a]	FCAT
Reading Fluency[a]	1.00			
Spelling[a]	.53*	1.00		
Reading Comprehension[a]	.54*	.42*	1.00	
FCAT	.63*	.48*	.66*	1.00

Note.

*p < .05

[a]FAIR

Table 3

Twin intraclass correlations for combined 3rd and 4th grade FAIR and FCAT scores.

	Twin intra-class correlations	
Variable	**MZ**	**DZ**
Reading Fluency[a]	.78*	.44*
Spelling[a]	.73*	.24*
Reading Comprehension[a]	.54*	.40*
FCAT	.79*	.52*

Note.

*p < .05

[a]FAIR

Table 4

Univariate estimates for heritability (h^2), additive genetic influences (a^2), dominance genetic influences (d^2), shared environment (c^2) and non-shared environmental (e^2) influences for combined 3rd and 4th grade FAIR and FCAT scores [with 95% confidence intervals].

ACE Model	**h^2**	**c^2**	**e^2**
Reading Fluency[a]	.65* [.46-.84]	.12 [.00-.29]	.23* [.18-.28]
Spelling[a]	.71* [.58-.83]	.00 [.00-.00]	.30* [.25-.38]
Reading Comprehension[a]	.28* [.03-.53]	.26* [.06-.45]	.46* [.38-.56]
FCAT	.52* [.35-.71]	.27* [.09-.44]	.21* [.17-.26]
ADE Model	a^2	d^2	e^2
Spelling[a]	.28 [.00-.72]	.43* [.01-.79]	.28* [.23-.35]

Note.

* indicates significance based on confidence intervals not bounding zero.

[a] FAIR

Table 5

Multivariate modeling path estimates results of genetic and environmental influences for combined 3rd and 4th grade FAIR and FCAT scores [with 95% confidence intervals].

	Shared Influences between Fluency, Spelling, Reading Comp and FCAT	**Shared Influences between Spelling, Reading Comp and FCAT**	**Shared Influences between Reading Comp and FCAT**	**Independent Influences on FCAT**
	A_1 [C.I.]	**A_2 [C.I.]**	**A_3 [C.I.]**	**A_4 [C.I.]**
Fluency[a]	.78* [.66-.88]			
Spelling[a]	.45* [.32-.57]	.65* [.56-.72]		
Reading Comp[a]	.46* [.29-.60]	.10 [.00-.24]	.17 [.00-.46]	
FCAT	.48* [.34-.61]	.15* [.03-.27]	.55 [.00-.63]	.00 [.00-.50]
	C_1	C_2	C_3	C_4
Fluency[a]	.40* [.16-.57]			
Spelling[a]	.25* [.03-.42]	.00 [.00-.22]		
Reading Comp[a]	.45* [.18-.65]	.00 [.00-.43]	.29 [.00-.43]	
FCAT	.48* [.24-.64]	.00 [.00-.36]	.12 [.00-.36]	.00 [.00-.26]
	E_1	E_2	E_3	E_4
Fluency[a]	.48* [.44-.54]			
Spelling[a]	.14* [.07-.23]	.55* [.50-.62]		
Reading Comp[a]	.01 [.00-.11]	.08 [.00-.18]	.68* [.62-.73]	
FCAT	.14* [.07-.21]	.06 [.00-.13]	.12* [.06-.18]	.42* [.38-.47]

Note.

*indicates significance based on confidence intervals not bounding zero.

[a]FAIR