

Little Evidence That Socioeconomic Status Modifies Heritability of Literacy and Numeracy in Australia

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Socioeconomic status (SES) has been found to moderate the influence of genes and the environment on cognitive ability, such that genetic influence is greater when SES is higher, and the shared environment is greater when SES is lower, but not in all Western countries. The effects of both family and school SES on the heritability of literacy and numeracy in Australian twins aged 8, 10, 12, and 14 years with 1,307, 1,235, 1,076, and 930 pairs at each age, respectively, were tested. Shared environmental influences on Grade 3 literacy were greater with low family SES, and no other moderating effects of SES were significant. These findings are contrasted with results from the United States and the United Kingdom.

Once the province of the wealthy, the 19th century heralded movements toward systemic education in European countries and the United States of America (Meyer, Tyack, Nagel, & Gordon, 1979; Ramirez & Boli, 1987). In Australia, there was a push for national, secular, and free education from the mid-1800s (Crane, 1951). Although compulsory primary education was introduced by the late 1800s, high school education remained academically selective and largely restricted to families who could afford the fees until reforms in 1911–1912 (Proctor, 2007). With education available to children from a broad range of economic backgrounds, debate on the influence of nature and nurture on the mental

ability and academic achievement of children moved from theoretical to empirical.

To counter arguments that were based on specific individuals who exhibited genius despite their origins, Kornhauser (1918) published a study demonstrating a positive quantitative association between wealth and school achievement. This positive correlation between socioeconomic status (SES) and academic outcomes has been confirmed in numerous studies (most conducted on children in the United States), and meta-analyses have found the size of this effect to be modest ($r = .27$, Sirin, 2005; $r = .22$, White, 1982). In recent years, the Organisation for Economic Co-operation and Development (OECD) Program for International Student Assessment (PISA) has found an association between SES and academic achievement in most OECD countries (Organisation for Economic Co-operation and Development, 2013). The strength of the association between SES and academic achievement differed across OECD countries, but it was similar in strength between Australia (12.3% of the variance), U.K. (12.5%), and U.S. (14.8%;

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Organisation for Economic Co-Operation and Development, 2013). Note that these effects reported from PISA are stronger than the meta-analyses; this might be evidence of a cohort effect, with SES having a stronger influence in more recent years, or it might be due to other study-specific factors, such as more representative sampling of the population in the PISA.

A major limitation in most studies of SES and academic achievement is the inability to distinguish the impact of SES on academic ability independent of innate influences on both. Genetic variation is a substantial contributor to individual differences in academic achievement; in developed countries, genes typically explain more than half of the variation in performance of these academic outcomes (de Zeeuw, de Geus, & Boomsma, 2015), and in Australia genetic influence on “high-stakes” assessment of literacy, language, and numeracy in Grades 3–9 has been shown to range from around 50% to near 80% of variance (Grasby, Coventry, Byrne, Olson, & Medland, 2016).

For SES, recent studies in the United Kingdom using genome-wide complex trait analysis have estimated the heritability at approximately 20%, which is underestimated by the extent that relevant sources of genetic variation, such as copy number polymorphisms and markers of methylation, are absent from the genotyping chips employed in the analyses (Marioni et al., 2014; Trzaskowski et al., 2014). Furthermore, genes have been found to mediate about half of the correlation between academic achievement and SES (Krapohl & Plomin, 2015). For this article, the correlation between academic achievement and SES, whether due to genes or the environment, will be considered a main effect of the measure of SES in predicting academic achievement.

In addition to a main effect, SES might moderate the influence of genes and the environment on academic achievement, resulting in a gene–environment interaction such that the influence of genes (or the environment) is different for people from different SES environments (Plomin, DeFries, & Loehlin, 1977). Thus far, few studies have explored whether family SES moderates the influence of genes and the environment on performance in literacy or numeracy, and these differ in age of participants and measures of achievement (Kremen et al., 2005; Rhemtulla & Tucker-Drob, 2012; van den Oord & Rowe, 1997). In one such study, Rhemtulla and Tucker-Drob (2012) showed heritability of early mathematical skills increased in 4-year-olds with increasing family SES. Tucker-Drob and Harden

(2012b) investigated this further and demonstrated that the interaction was mediated by genetic variation in motivation to learn. They suggested the individuals with higher SES, perhaps through access to more resources, were able to translate their motivation to learn into better mathematical performance. This actualizing of genetic potential in a better environment is consistent with the bioecological model of development detailed by Bronfenbrenner and Ceci (1994).

The bioecological model predicts heritability to be greater in more advantageous environments and constrained in impoverished environments. Although the environmental disadvantage hypothesis also predicts constrained heritability in impoverished environments (Scarr-Salapatek, 1971), the bioecological model extended this prediction across the environmental range. Although not specifically assessing literacy or numeracy, Harden, Turkheimer, and Loehlin (2007) showed heritability of a latent construct of academic aptitude in 17-year-olds increased with increasing family income, and Tucker-Drob and Harden (2012a) demonstrated that this interaction was mediated by intellectual interest. Importantly, the families in Harden et al.’s (2007) study reported higher average SES than the population thus demonstrating an interaction between genes and the environment across relatively advantageous levels of the measured environment. More recently, this interaction where the shared environment (factors that are shared by twins raised in the same family) explains most of the variation when SES is low and genes explain most of the variation when SES is high has been termed the Scarr–Rowe interaction (Turkheimer, Harden, D’Onofrio, & Gottesman, 2009).

In some studies the Scarr–Rowe interaction has not been evident. In contrast to early mathematical skills, no interaction with SES was found for heritability of early reading skills in 4-year-olds (Rhemtulla & Tucker-Drob, 2012), indicating possible differences between these academic domains. In school-aged children, approximately 9.5 years old, van den Oord and Rowe (1997) examined a range of home SES factors and found little evidence for moderation of the heritability of either reading or mathematics. Finally, a different type of environment–environment interaction was noted in a study on reading ability in middle-aged adult men, such that environmental variance decreased with increasing childhood SES (Kremen et al., 2005). This finding is unusual in which environmental influence from both factors shared by twins and factors unique to individuals reduced as SES increased.

This particular study indicates that childhood SES can have an enduring impact on environmental influences on reading skills throughout life; however, measuring SES in childhood and reading in adulthood makes this study quite unlike others on the moderating effect of SES on heritability. From so few studies, it is not possible to determine if the differences are due to different domains being assessed, age, or other study factors.

Although there are few studies with literacy or numeracy as outcomes, there is a growing body of research assessing the moderating impact of SES on cognitive ability, and there is some evidence that the variance that is moderated by SES in literacy and numeracy is in common with general cognitive ability (Turkheimer et al., 2009). Increasing heritability with increasing family SES has been reported at a various ages, including infancy (Tucker-Drob, Rhemtulla, Harden, Turkheimer, & Fask, 2011), childhood (Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003), early adolescence (Fischbein, 1980), late adolescence (Harden et al., 2007; Rowe, Jacobson, & Van den Oord, 1999), and adulthood (Bates, Lewis, & Weiss, 2013). Consistent with the Scarr–Rowe interaction, several of these studies also report an environment–environment interaction such that the influence of the shared environment decreases with increasing SES (e.g., Rowe et al., 1999; Tucker-Drob et al., 2011; Turkheimer et al., 2003). Interestingly, in the most powerful gene–environment SES moderation study to date, Hanscombe et al. (2012) assessed cognitive ability in a longitudinal study in the United Kingdom at eight different ages, ranging from 2 to 14 years old. The most consistent result was decreasing shared environment and no significant change in heritability with increasing SES. This indicated an SES-dependent, differential effect of the shared environment on cognitive ability without the fostering of genetic potential in more advantaged environments. Complimenting these findings from twin studies, family SES did not interact with genome-wide polygenic scores for educational attainment to explain educational achievement in 16-year-olds in the United Kingdom (Selzam et al., 2016). This approach specifically assesses if genetic variation is interacting with family SES to influence academic achievement but does not assess an environmental interaction with family SES.

Again, as with academic achievement, some studies have found no significant gene–environment or environment–environment interaction. In the only study to date from Australia, SES did not moderate heritability of IQ in adolescents (16 years

old; Bates, Hansell, Martin, & Wright, 2016). Similarly in the United States, Grant et al. (2010) found no moderation of cognitive ability in young adult men (19 years). Interestingly, this was a large sample, a subset of which formed the participants in Kremen et al.'s (2005) study. These two studies used the same measure for SES, and although Grant et al. found no moderation on general cognitive ability at age 19, Kremen et al. did find an environment–environment interaction between SES and reading ability assessed approximately 30 years later. The different findings from these two studies might result from tests administered at different ages or perhaps reflect different interactions with SES for cognitive ability and reading. That specifics regarding age or cohort might contribute to differing results is apparent in van der Sluis, Willemsen, de Geus, Boomsma, and Posthuma (2008) study in the Netherlands, where an environment–environment interaction on the heritability of IQ was found for men in an older cohort (average age 49) but not for men in a younger cohort (average age 26) or for women in either cohort.

Along with age and specific ability measured, some of the inconsistencies evident in the available data may be due to national context. Following on from earlier suggestions that cross-national differences may determine the extent of gene–environment interaction (e.g., Bates et al., 2013; Hanscombe et al., 2012; Turkheimer et al., 2009), Tucker-Drob and Bates (2015) conducted a meta-analysis of Gene \times SES interaction on intelligence and academic achievement and demonstrated that studies conducted in the United States tended to show the interaction predicted by the Scarr–Rowe interaction, whereas those originating in Western Europe and Australia did not. They advanced a variety of ideas that may explain the international discrepancy, such as educational quality and access, health support, and social mobility but appropriately treated these as candidates for future research rather than firm conclusions.

Although studies on cognitive ability have focused on family SES as a moderator of heritability, heritability of academic outcomes such as literacy and numeracy are potentially more dependent on variation in instruction and school resources. In the only study to date using school SES as a moderator, Hart, Soden, Johnson, Schatschneider, and Taylor (2013) found heritability was higher in reading performance for twins attending lower SES schools, which is in the opposite direction to the effect more frequently reported. But consistent with other studies, they noted that the shared

environment and total variance were greater in lower SES schools. The authors suggest schools with more resources might be more similar on various characteristics that facilitate reading proficiency in all students. Although it is important to not overinterpret this singular finding, in a study from the same project (the Florida Twin Project on Reading) the heritability of oral reading fluency in slightly younger twins was found to significantly increase with greater class gains in reading over the course of the teaching year (Taylor, Roehrig, Hensler, Connor, & Schatschneider, 2010). It is not easy to explain the opposite direction of the interactions from these two studies that assess aspects of school environments as moderators of heritability, and replication in future studies might help to clarify these contradictory findings.

In this article, we will assess if SES moderates the heritability of literacy and numeracy in school-aged children in Australia. Each year the National Assessment Program in Literacy and Numeracy (NAPLAN) tests are administered to students in Grades 3, 5, 7, and 9 in five academic domains: reading, spelling, grammar and punctuation, writing, and numeracy. As indicated earlier, genetic variation has been found to substantially contribute to variation in performance on the NAPLAN, whereas the influence of the shared environment was low to modest (Grasby et al., 2016). However, if a gene-SES interaction is present, then estimates from the standard twin model will be biased; specifically, estimates of genetic effects will be inflated (Purcell, 2002).

SES is an extensively researched construct, and numerous methods have been used to operationalize it in research. Ideally, a measure of family SES incorporates parent education, occupation, and income, each of which have been shown to contribute uniquely to child academic outcomes (White, 1982). We have a measure of parent education to use as a proxy for family SES; although imperfect, there are several strengths to this measure. Parental education is the most commonly used SES measure when assessing the effect of SES on academic performance; thus, our work will be comparable to the broader field (Sirin, 2005; Tucker-Drob & Bates, 2015). Level of education is the most stable measure out of education, occupation, and income, and stability is important given the longitudinal nature of the study. Although parent education is not a nuanced measure of SES, including a measure of school SES will contribute to a more comprehensive picture of the effect of SES on literacy and numeracy.

To tease apart the possibility that family and school SES have a differential impact on moderating heritability, the current study will first assess the effect of family SES and then test school SES as an influence over and above that of the family. We will assess school SES in this hierarchical way for two reasons: First, family and school SES are correlated, but family SES is more stable and has operated on child outcomes for a longer period of time than school SES. A hierarchical approach will assess the influence of school SES while controlling for the family SES. Second, because twins share family SES, it is not possible with the twin model to estimate the genetic correlation between parental education and child literacy and numeracy. A genetic correlation will inflate the influence of the shared environment and potentially confound moderating effects of school SES if family SES is not included when assessing the effects of school SES. Given the Tucker-Drob and Bates (2015) findings and our data set being Australian, we might not find a Gene \times SES interaction with academic achievement. However, given we employ both family- and school-based indices of SES, uncertainties remain, in particular regarding the potential influence of our novel instrument assessing school SES. This will extend current research across the middle years of school, using important school outcomes as measures, and a sample relevant to the Australian context.

Method

Participants

Participants were part of the longitudinal study "The Australian Twin-Study of the NAPLAN," twins and triplets were recruited through the voluntary Australian Twin Registry. Data were collected from 2012 to 2016. After participants consent, the states provided all available NAPLAN results for each participant, thus the calendar years of NAPLAN data collected ranged from 2008 to 2016. For the 40 sets of triplets, a random pair from each set was selected, and from here on all pairs will be referred to as "twins." NAPLAN and zygosity data were available for 2,198 pairs. Most participants attended the same school in the same year as their cotwin: 97.6% in Grade 3, 95.6% in Grade 5, 91.5% in Grade 7, and 88.7% in Grade 9. Dizygotic (DZ) twins were more likely to attend different schools or be in different grades, so only twins who were in the same school and grade in the same year were included for these analyses. A further 2% were excluded due to missing data on measures of

family or school SES, resulting in 1,311 twin pairs in Grade 3 (618 monozygotic [MZ] pairs), 1,239 in Grade 5 (564 MZ pairs), 1,080 in Grade 7 (509 MZ pairs), and 932 in Grade 9 (482 MZ pairs). Zygosity was determined by parent report of a DNA test or with a short questionnaire (Lykken, Bouchard, McGue, & Tellegen, 1990). A substantial number of participants provided results from more than one grade: 77.7% in Grade 3, 96.6% in Grade 5, 98.4% in Grade 7, and 83.0% in Grade 9, although only 12.7% of the sample had results for all grades. The average age in Grade 3 at the time of testing was 8.6 years and tests were 2 years apart.

Materials

National Assessment Program in Literacy and Numeracy

The NAPLAN is a nationwide assessment of students in Grades 3, 5, 7, and 9 on standardized tests of reading comprehension, writing, grammar and punctuation, spelling, and numeracy. Scores range from 0 to 1,000 and are calibrated to be compared with previous cohorts and across grades. Example papers and technical reports are available at www.nap.edu.au

Literacy

The reading test requires students to read 7–8 passages and answer comprehension questions about the passages. The language conventions test assesses spelling, grammar, and punctuation; students are required to identify and correct misspelled words, to identify or insert punctuation marks in sentences, and to select correct word(s) to complete sentences. Tests are predominantly multiple choice with some short answer questions. The writing test presents a prompt and requires students to write several paragraphs in a specified style (i.e., narrative, informative, or persuasive). Cohort and age effects (age, age squared, and Age \times Sex) were regressed out of NAPLAN scaled scores, and scores standardized within domain prior to obtaining a mean literacy score.

Numeracy

The numeracy test assesses aspects of mathematics including working mathematically, number, algebra, function, pattern, measurement, chance, data, and space. Most items are multiple-choice format, with a few short answer questions in each test.

In Grades 3 and 5 students sit one numeracy test, and in Grades 7 and 9 students sit a numeracy test that allows calculator use and one that does not.

Family SES

Level of parent education achieved was used as a measure of family SES. Parents were asked to select a level of education from: (a) some high school but did not finish, (b) school certificate, (c) higher school certificate, (d) TAFE or trade (including certificate or diploma), (e) 3-year university degree, (f) 4-year university degree, (g) some post-graduate study, (h) master's degree, and (i) doctoral degree. Note that in Australia, TAFE stands for Technical And Further Education institutes, which typically provide vocational training at the certificate and diploma level, and at the time the parents were educated, both school certificate in Grade 10 and higher school certificate in Grade 12 were legitimate exit points to graduate from secondary schooling. These responses were scored from 1 to 9. Mother and father education correlated .44, and an average parent education level was obtained and used in analyses.

School SES

The Index of Community Socio-Educational Advantage (ICSEA) was used as a measure of the SES level of each school. ICSEA values are reported each year for each school by Australian Curriculum Assessment and Reporting Authority, and predict average school performance on the NAPLAN. The value incorporates family and community variables, including parent occupation and education, school location (metropolitan, regional, or remote), proportion of indigenous students, and proportion of students with a disadvantaged language background other than English (LBOTE). Not all LBOTE students are disadvantaged; on average they outperform non-LBOTE students, but there are some particularly disadvantaged groups within the broader LBOTE group, and they were identified by combining LBOTE with parents who have an education level of Grade 9 or below. In 2008 and 2009, census data were used to calculate the ICSEA, and since 2010 family data collected by schools has been used where possible. The weight of each variable that contributes to the ICSEA value is calculated using stepwise regression (for more details, see Australian Curriculum Assessment and Reporting Authority, 2015; Barnes, 2011). The Australian median is 1,000 with a standard deviation of 100. A

higher score indicates a school with higher educational advantage.

Procedure

NAPLAN tests are administered in the morning over 3 consecutive days each year in the second full week of May (approximately 3.5 months into the school year). Two tests are administered on the first day, the language conventions test (comprising the spelling and grammar and punctuation domains) followed after a break by the writing test. On the second day, the reading test is administered. On the third day, the numeracy tests are administered. Across the nation 96% of students participate in the tests.

Analyses

Prior to conducting the twin models, assumption testing on the literacy and numeracy measures indicated sex effects on the variances and covariances in some grades, thus sex-limitation models were run to test if it was appropriate to combine female and male students for the subsequent analyses. Details on these tests are in Data S1.

A continuous univariate gene–environment interaction model was used to estimate both school and family moderation of SES on genetic and environment variation in NAPLAN performance (Purcell, 2002). This model builds on the standard ACE twin model, which partitions variance into additive genetic (A), shared environmental (C), and unique environmental (E) components. Given that MZ twins share all and (on average) DZ twins share half their genes, the covariance of A within pairs was fixed at 1.0 for MZ twins and 0.5 for DZ twins. As shared environmental influences are common to both twins in a pair regardless of zygosity, the covariance of C within pairs was fixed at 1.0 for both MZ and DZ twins. Unique environmental components do not covary within pairs. In the gene–environment interaction model, each of the a , c , and e paths were moderated by SES (either family or school). Where sex-limitation testing found a significant difference between female and male students in the relative influence of genes and the environment, then sex was included as a second moderator on the variance components along with the interaction of SES \times Sex. A simplified path diagram (without the interaction term) of the model is depicted in Figure 1. Unmodeled gene–environment correlation can resemble gene–environment interaction (Purcell, 2002), and there is evidence that

covariation between family SES and academic achievement is substantially due to shared genes (Krapohl & Plomin, 2015). In our model we are unable to test for gene–environment correlation, as twins share each of the moderators used in this study. Thus, we controlled for gene–environment correlation by including the moderator in the means. Including the moderator in the means removes from the total variance the covariation between the moderator and the outcome; as such the gene–environment interaction model estimates the influence of A, C, and E as a function of the moderator on the variance in the outcome that is independent of the main effect of the moderator (Purcell, 2002). As we were interested in the effect of school SES over and above family SES, family SES was included in the means when testing school SES as a moderator.

The significance of SES as a moderator of A, C, and E was tested using the likelihood ratio test, which compares the change in log likelihood to a chi-square distribution with degrees of freedom equal to the difference in estimated parameters (Neale & Maes, 2004). When sex was included as a second moderator in the model, then a sequence of nested models was tested. First, the interaction terms of SES and sex were dropped from A, C, and E. Then, sex was dropped as a moderator from A, C, and E; if this was significant, then sex was kept

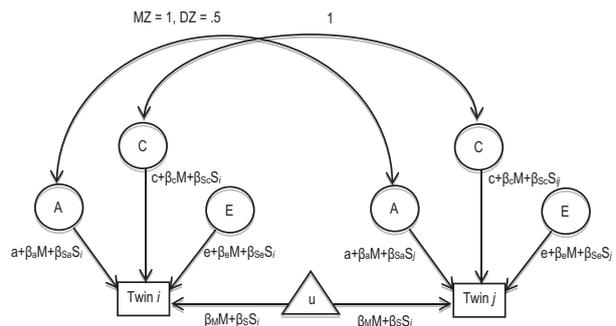


Figure 1. Path diagram of the moderation model. Genetic variance (A), shared environmental variance (C), and unique environmental variance (E) are estimated as the sum of the unmoderated effect with the effect of the moderator and any sex effects (where appropriate). The value of the moderator (M; either family or school socioeconomic status) is the same for each twin within a family. The moderator is multiplied by either β_M , β_a , β_c , or β_e , which estimate the effect of the moderator on the mean (u), A, C, and E, respectively. Twins in a pair may differ on sex, S_i and S_j , respectively, represent the sex of Twin i and Twin j , which is multiplied by the appropriate β_S , β_{Sa} , β_{Sc} , or β_{Se} estimate of sex effects. The genetic correlation for monozygotic (MZ) twins is fixed at 1 and for dizygotic (DZ) twins is fixed at .5, whereas the shared environment correlation is fixed at 1 for all twins.

as a moderator on the variance components of subsequent models. Finally, SES was dropped as a moderator from A, C, and E. There is reduced power to detect the significance of individual moderating parameters in the presence of another (Purcell, 2002). Therefore, moderating parameters were dropped individually and the best-fitting model was determined as the model with the lowest Akaike's information criterion (Akaike, 1987) that included significant moderating parameters from the individual tests. *Z* scored data of traits and SES moderators were used in the gene–environment interaction models. Models were estimated using raw data and full information maximum likelihood estimation in OpenMx, which uses all available data (Boker et al., 2011).

Results

Four families with school SES outliers were removed from Grades 3, 5, and 7, and two were removed from Grade 9; there were no outliers on family SES. Means, standard deviations, and number of individuals for each moderator and domain by grade are reported in Table 1. On average, our sample is about 0.5 *SD* above the nation in school educational advantage, suggesting a more advantaged sample than the population for school SES. Our sample also reported a higher level of education than that reported by the Australian Bureau of Statistics for people aged 15–74; however, people over 55 years of age are less likely than younger cohorts to have postschool qualifications (Australian Bureau of Statistics, 2014). In our study, the educational level of parents with postschool qualifications is proportional to those of the population who are of 25–54 years old (the equivalent age cohorts of the parents of twins in our study). Therefore, our sample represents a higher than average school SES, but is similar to the Australian population in family SES.

Descriptive statistics and phenotypic correlations between SES and literacy and numeracy are reported in Table 1. The correlations between family SES and literacy and numeracy were modest, and partial correlations between school SES and literacy and numeracy, controlling for family SES, were small but significant in each grade. These indicate a small, positive correlation between school advantage and performance that is independent of family SES.

The partitioning of variation in literacy and numeracy performance into genetic, shared

Table 1

Descriptive Statistics and Phenotypic Correlations Between National Assessment Program in Literacy and Numeracy Domains and SES Measures

Variable	Descriptive statistics			Correlations	
				SES	
	<i>M</i>	<i>SD</i>	<i>n</i>	Family	School ^a
Grade 3					
Literacy	437	65	2,613	.30	.15
Numeracy	423	69	2,586	.31	.14
Family SES	4.8	1.6	2,614	—	—
School SES	1,054	75	2,614	.41	—
Grade 5					
Literacy	522	59	2,469	.31	.16
Numeracy	511	69	2,441	.30	.18
Family SES	4.6	1.6	2,470	—	—
School SES	1,052	75	2,470	.41	—
Grade 7					
Literacy	570	57	2,151	.30	.19
Numeracy	574	69	2,128	.29	.16
Family SES	4.6	1.6	2,152	—	—
School SES	1,045	72	2,152	.40	—
Grade 9					
Literacy	612	59	1,858	.29	.20
Numeracy	627	68	1,828	.31	.22
Family SES	4.6	1.7	1,860	—	—
School SES	1,047	73	1,860	.43	—

Note. All correlations were significant at $p < .01$. *n* = number of individuals; SES = socioeconomic status. ^aPartial correlations controlling for family SES.

environmental, unique environmental, family SES, and school SES is reported in Table 2. The percentage of variance in NAPLAN performance due to the main effect of family SES was 9% when averaged across both literacy and numeracy, and all grades and sexes. After removing the effect of family SES, school SES accounted for an extra 1%–5% of the variation in NAPLAN test performance. Sex-limitation models showed that female and male students could not be equated without a significant loss of model fit for literacy in Grades 3 and 9, or for numeracy in any grade. Model-fitting statistics are in Table S1. For literacy in Grade 9 and all of the numeracy results, the best-fitting model was a scalar model, which allowed boys to vary more than girls but have equivalent relative influences from A, C, and E. Therefore, only for literacy in Grade 3 was sex included as a second moderator in the subsequent analyses. The estimates of A, C, and E, with the effect of SES partitioned out, are reported in Table 2.

Family SES was a significant moderator of Grade 3 literacy. Sex was also a significant moderator, but the interaction of sex and family SES could be dropped without significant loss of model fit (model-fitting statistics are in Table 3). Testing of individual moderation paths indicated that family SES significantly moderated the shared environment, as family SES increased the influence of the shared environment decreased. The direction of sex effects indicated less genetic effects and more environmental effects on literacy performance in boys than in girls. No other grade showed significant moderation of literacy by family SES. There was no significant moderation of numeracy by family SES, and no moderation of either numeracy or literacy by school SES. Model-fitting statistics for school SES are in Table 4, and parameter estimates are reported in Table 5.

Figure 2 displays the moderation of literacy and numeracy for each grade with either family or school SES as the moderator. As scores were standardized within grade and domain, the relative influence of A, C, and E can be compared but not the total variance. The lack of moderation is evident in the generally flat variance components across the SES distributions. Although there were significant sex effects on the Grade 3 literacy, only the shared environment was significantly moderated, and in the absence of any interaction between family SES and sex on moderation of the variance components, this resulted in a simple difference in effect, with more shared environmental variance in boys for the moderator to act on. For boys in Grade 3 with low family SES, the shared environment accounted for 36% of the variance in literacy, whereas for girls it

accounted for 26%. For boys with mean family SES, the shared environment accounted for 12% of the variance in literacy, whereas for girls it accounted for 4%. For both sexes the effect of the shared environment reduced to no effect in families with high SES. Given these small differences in effect size, we have presented in Figure 2 the moderation of A, C, and E variance components with girls and boys combined.

Discussion

The main finding in this study, across both family and school SES, was one of no moderation of genetic influences by SES. The only exception was that family SES was found to moderate the shared environmental influence on Grade 3 literacy performance, such that there was a stronger influence of the shared environment when family SES was lower. This effect translates to a change in the influence of the shared environment from about 30% among students whose parents did not complete high school, down to about 10% when parents averaged a 3-year university degree, and no effect when parents had postgraduate study. However, in later grades this moderating effect from the shared environment was no longer evident.

Unlike some studies conducted in the United States, our main finding across all domains and grades was that genetic variation, at least, did not vary as function of either family SES or school SES in these Australian NAPLAN tests. There is no evidence of constrained genetic potential in children attending less advantaged schools or who have parents with less education. Given that our data are from families who volunteer to participate in research, we acknowledge that our data may not capture extreme environmental disadvantage. However, as the bioecological model is relevant to changes in heritability across the normal range of environmental advantage, it was interesting to find no evidence of advantageous family and school environments potentiating genetic expression. Although our Grade 3 literacy results are in the same direction as Hanscombe et al.'s (2012) study from the United Kingdom on cognitive ability, Hanscombe et al. found more consistent evidence of greater shared environmental influences with lower SES than we did. This decrease in the influence of the shared environment with increasing SES is also found in the broader research on cognitive ability in the United States (e.g., Rowe et al., 1999; Tucker-Drob et al., 2011; Turkheimer et al., 2003).

Table 2
Variance Partitioned Into A, C, and E and Main Effects of SES

Variable	A	C	E	Family SES	School SES
Literacy					
Grade 3 females	.73	.01	.16	.09	.01
Grade 3 males	.56	.08	.23	.09	.04
Grade 5	.66	.04	.18	.10	.03
Grade 7	.70	.00	.18	.09	.03
Grade 9	.70	.00	.19	.09	.03
Numeracy					
Grade 3	.61	.02	.27	.09	.01
Grade 5	.57	.09	.24	.08	.03
Grade 7	.74	.00	.18	.07	.02
Grade 9	.54	.10	.21	.10	.05

Note. A = additive genetic variance; C = shared environment variance; E = unique environment variance; SES = socioeconomic status.

Table 3
 Model-Fitting Statistics for Family SES as a Moderator of Literacy and Numeracy in Grades 3, 5, 7, and 9

Subject	Grade	Model	Model description	<i>k</i>	-2LL	<i>df</i>	AIC	Δ -2LL	Δdf	<i>p</i>	Models compared
Literacy	3	1	Full model	16	5,537.60	2,597	343.60	—	—	—	—
		2	SES and sex mod ACE	13	5,539.35	2,600	339.35	1.75	3	.626	1 and 2
		3	SES mod ACE	10	5,554.59	2,603	348.59	15.24	3	.002 ^b	2 and 3
		4	Sex mod ACE	10	5,551.48	2,603	345.48	12.13	3	.007 ^b	2 and 4
		5	SES mod CE ^a	12	5,539.36	2,601	337.36	0.00	1	.964	2 and 5
		6	SES mod AE ^a	12	5,544.59	2,601	342.59	5.24	1	.022 ^b	2 and 6
		7	SES mod AC ^a	12	5,539.97	2,601	337.96	0.61	1	.434	2 and 7
		8	SES mod E ^a	11	5,549.53	2,602	345.53	10.18	2	.006 ^b	2 and 8
		9	SES mod C^a	11	5,540.03	2,602	336.03	0.68	2	.714	2 and 9
		10	SES mod A ^a	11	5,544.88	2,602	340.88	5.53	2	.063	2 and 10
	5	1	SES mod ACE	10	5,116.18	2,459	198.18	—	—	—	—
		2	ACE	7	5,118.01	2,462	194.01	1.83	3	.608	1 and 2
	7	1	SES mod ACE	10	4,485.37	2,141	203.37	—	—	—	—
		2	ACE	7	4,489.93	2,144	201.93	4.56	3	.207	1 and 2
9	1	SES mod ACE	10	3,996.43	1,848	300.43	—	—	—	—	
	2	ACE	7	3,998.40	1,851	296.40	1.96	3	.580	1 and 2	
Numeracy	3	1	SES mod ACE	10	6,552.91	2,576	1,400.91	—	—	—	—
		2	ACE	7	6,555.33	2,579	1,397.32	2.41	3	.491	1 and 2
	5	1	SES mod ACE	10	6,071.14	2,431	1,209.14	—	—	—	—
		2	ACE	7	6,078.04	2,434	1,210.04	6.91	3	.075	1 and 2
	7	1	SES mod ACE	10	5,181.80	2,118	945.80	—	—	—	—
		2	ACE	7	5,183.61	2,121	941.61	1.81	3	.613	1 and 2
	9	1	SES mod ACE	10	4,483.13	1,818	847.13	—	—	—	—
		2	ACE	7	4,487.07	1,821	845.07	3.94	3	.268	1 and 2

Note. Full model moderates A, C, and E by SES, sex, and Sex × SES. *k* = number of parameters estimated; -2LL = minus 2 log likelihood; *df* = degrees of freedom; AIC = Akaike's information criterion; Δ = change; SES = family socioeconomic status. ^aSex retained as a moderator on the A, C, and E variance components. ^bSignificant loss of fit. Bold indicates the best fitting model for Grade 3 literacy.

Table 4
 Model-Fitting Statistics for School SES as a Moderator of Literacy and Numeracy in Grades 3, 5, 7, and 9

Subject	Grade	Model	Model	<i>k</i>	-2LL	<i>df</i>	AIC	Δ -2LL	Δdf	<i>p</i>	Models compared
Literacy	3	1	SES mod ACE	12	5,515.78	2,601	313.78	—	—	—	—
		2	ACE	9	5,516.80	2,604	308.80	1.03	3	.795	1 and 2
	5	1	SES mod ACE	12	5,072.64	2,457	158.64	—	—	—	—
		2	ACE	9	5,073.86	2,460	153.86	1.22	3	.748	1 and 2
	7	1	SES mod ACE	12	4,431.15	2,139	153.15	—	—	—	—
		2	ACE	9	4,434.46	2,142	150.46	3.31	3	.346	1 and 2
9	1	SES mod ACE	12	3,950.76	1,846	258.76	—	—	—	—	
	2	ACE	9	3,953.50	1,849	255.50	2.74	3	.433	1 and 2	
Numeracy	3	1	SES mod ACE	12	6,515.40	2,574	1,367.40	—	—	—	—
		2	ACE	9	6,515.94	2,577	1,361.94	0.54	3	.911	1 and 2
	5	1	SES mod ACE	12	6,018.87	2,429	1,160.87	—	—	—	—
		2	ACE	9	6,025.11	2,432	1,161.11	6.24	3	.100	1 and 2
	7	1	SES mod ACE	12	5,142.77	2,116	910.77	—	—	—	—
		2	ACE	9	5,143.33	2,119	905.33	0.56	3	.905	1 and 2
	9	1	SES mod ACE	12	4,424.65	1,816	792.65	—	—	—	—
		2	ACE	9	4,426.63	1,819	788.63	1.97	3	.578	1 and 2

Note. *k* = number of parameters estimated; -2LL = minus 2 log likelihood; *df* = degrees of freedom; AIC = Akaike's information criterion; Δ = change; SES = family socioeconomic status.

Table 5

Unstandardized Parameter Estimates of ACE Model Moderated by Family SES and Sex for Literacy and Numeracy

Variable	Unmoderated			SES			Beta effects on the means				
	<i>a</i>	<i>c</i>	<i>e</i>	<i>a</i>	<i>c</i>	<i>e</i>	Sex	Family SES	Family SES × Sex	School SES	School SES × Sex
Family SES											
Literacy											
Grade 3	.69 f. 64 m	.16 f. 28 m	.33 f. 41 m	0	-.15*	-.01	-.14*	.26*	0	—	—
Grade 5	.68	.21	.35	.01	-.05	-.01	-.16*	.25*	.03	—	—
Grade 7	.71	0	.35	-.03	0	.02	-.14*	.25*	.02	—	—
Grade 9	.73	0	.37	-.02	0	0	-.08	.25*	0	—	—
Numeracy											
Grade 3	.78	.18	.52	-.01	-.01	.02	.10*	.29*	.04	—	—
Grade 5	.74	.34	.49	.04	-.01	.01	.15*	.26*	.09*	—	—
Grade 7	.86	0	.41	.03	0	0	.17*	.25*	.08	—	—
Grade 9	.74	.36	.46	-.01	-.01	.03	.08	.28*	.04	—	—
School SES											
Literacy											
Grade 3	.69	.14	.37	-.01	-.02	.01	-.15	.22*	-.05	.08*	.11*
Grade 5	.68	.12	.35	-.02	.09	0	-.16	.20*	.02	.12*	.04
Grade 7	.70	0	.35	-.03	0	.01	-.13	.20*	-.02	.12*	.09*
Grade 9	.72	0	.37	-.02	0	-.01	-.07	.18*	-.01	.17*	.02
Numeracy											
Grade 3	.77	.15	.52	0	-.05	.01	.10	.25*	.01	.11*	.09*
Grade 5	.75	.21	.48	.01	.14	.01	.15	.19*	.07*	.16*	.04
Grade 7	.84	.06	.42	.01	-.07	-.01	.17	.20*	.05	.13*	.08
Grade 9	.74	.30	.46	-.01	.01	.02	.09	.18*	.04	.24*	0

Note. SES = socioeconomic status; *a* = additive genetic; *c* = shared environment; *e* = unique environment; f = females; m = males. **p* < .05.

Our findings of no effect for the shared environment beyond Grade 3 are consistent with the other Australian study, which found SES did not moderate the influence of either genes or the environment on variation in IQ in 16-year-olds (Bates et al., 2016). Our results broadly support the hypothesis that gene-environment interactions in academic achievement and cognitive ability are typically found in the United States but not in other Western countries (Tucker-Drob & Bates, 2015).

The general finding of no moderation in our Australian data, as compared to significant results in both the United States and United Kingdom, might result from cross-country differences. Although we cannot test with these data what these factors are, we propose how differences in education and health care might contribute to these different findings. The literacy and numeracy tests in Australia were developed to assess competency in literacy and numeracy and were based initially on national *statements of learning* and then on the national curriculum (Donnelly & Wiltshire, 2014). As such, there is explicit instruction on the skills

assessed in this study, and if adherence to curricula is effective at a national level, then instruction ought to be somewhat systematic throughout the sample. Similarly, but for a longer period of time than in Australia, the United Kingdom has an established centralized education system, with a national curriculum introduced in 1989 (Whetton, 2009). Meanwhile, in the United States there has been a relatively recent move toward a national standard, with the Common Core State Standards Initiative (Kornhaber, Griffith, & Tyler, 2014). These Common Core State Standards differed considerably from existing standards in many states (Porter, McMaken, Hwang, & Yang, 2011). Considering the recency of adopting a common standard in the United States, the increasing heritability with increasing SES noted in the United States might reflect differences in educational standards across the population. Importantly, there is evidence that the United States has a greater disparity in provision of quality teaching and educational resources based on SES than other developed countries (Akiba, LeTendre, & Scribner, 2007; Darling-Hammond, 2014;

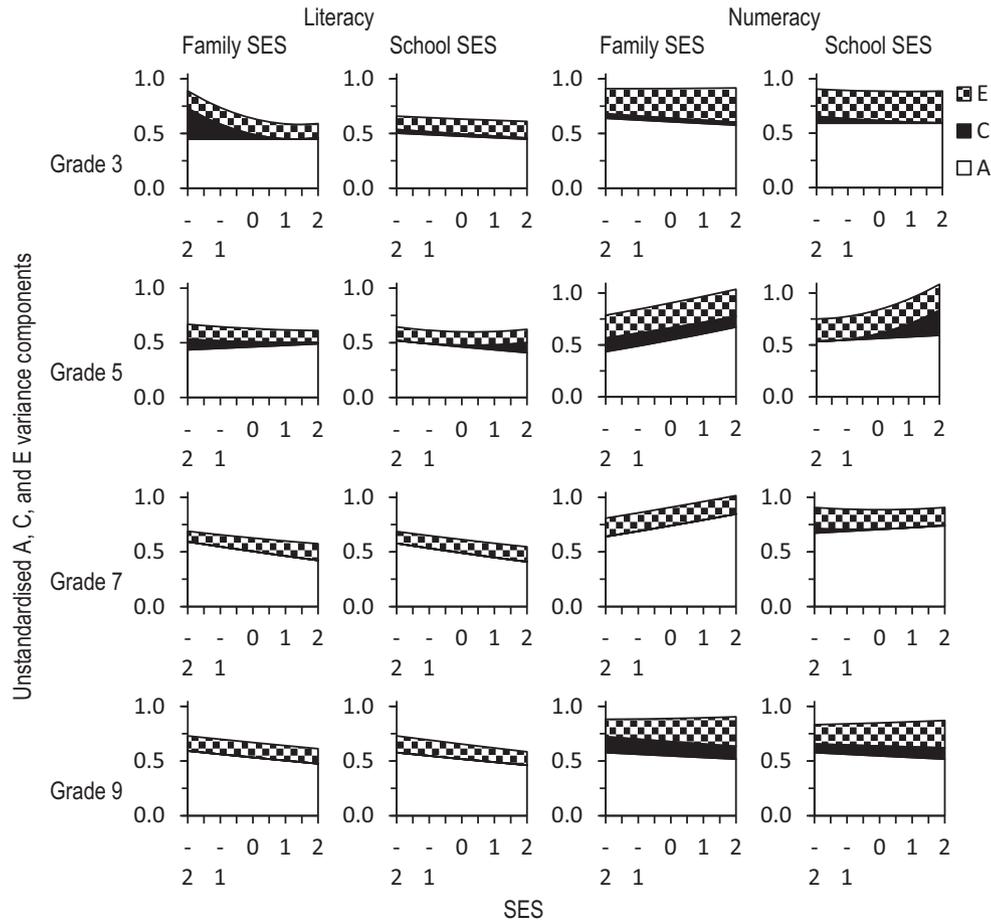


Figure 2. Figures of family and school socioeconomic status (SES) moderating additive genetic (A), shared environmental (C), and unique environmental (E) unstandardized variance components of literacy and numeracy in each grade. SES, literacy, and numeracy scores were all standardized. Figures depict the amount of variance explained by A, C, and E at different levels of SES.

Organisation for Economic Co-Operation and Development, 2009). Therefore, compared to Australia, U.S. has both more variation in educational standards, and the access to higher standards has been greater for children with higher SES, potentially culminating in greater expression of genetic variation for those with greater resources and a constriction of genetic expression for those with less. Thus, we speculate that a more equitable provision of quality education in Australia results in genetic variation as an important influence on performance regardless of SES.

To compound further the differences in educational opportunity, access to health care is markedly different in the United States compared to U.K. and Australia. U.S. is not a poor country, but it has one of the highest rates of child poverty among OECD countries (Organisation for Economic Co-Operation and Development, 2009). Furthermore, poorer families in the United States report significantly poorer

access, wait times, quality, and ability to follow-up with treatment due to costs than higher SES families, although this is not the case in Australia and U.K. (Schoen & Doty, 2004). Future research could direct efforts to assessing if measures of equitable access to quality education health care are mediators of the relationship between not just the main effect of SES on literacy and numeracy but of the moderating effects.

Consistent with broader research into SES and academic achievement, both family and school SES were related to NAPLAN performance as a main effect. Family SES accounted for 9% of the total variation in NAPLAN performance in our data. Over and above this family effect, school SES contributed only 1%–5% of the variation. These main effects are not solely a measure of the shared environment; genetic correlations between SES and academic achievement identified in genome-wide studies (Krapohl & Plomin, 2015) indicate that some

of this main effect is due to systematic genetic differences along the distribution of SES. The significant main effects between SES and literacy and numeracy without SES moderating the remaining variance indicates that SES is related to performance through factors that differ between lower and higher SES but do not differ within an SES level. The large main effect for family SES indicates that this is particularly the case for family SES.

Limitations

There are several limitations with the current study. One limitation is power. Although our sample is larger in size to many that have assessed gene-environment interaction effects, it is underpowered. There are two problems with low power: There might not have been power to detect an effect of moderation in these data, and the effect size found of moderation of the shared environmental effect on Grade 3 literacy might overestimate the true effect. Although this is a limitation, these findings have an important contribution to the field. There is, to date, no other sample assessing the behavior genetic influences on literacy and numeracy in Australian children through their middle years of school. The country differences found by Tucker-Drob and Bates (2015) emphasized the need for data from more countries than U.S., and these findings will make an important contribution to future meta-analyses.

Another limitation is that our sample was more representative of the middle and upper levels of SES than of lower SES in Australia. Our sample is similar to that of the wider Australian population on level of parental education attained; however, it is drawn from families who voluntarily register to participate in research and is unlikely to represent the entire distribution of families in the population. For example, it is unlikely that many of our participants come from extremely disadvantaged homes. The distribution of our school advantage values indicate that our sample attended schools that are generally more advantaged than the wider population; for example, 2 *SDs* below the mean in our sample is equivalent to only 1 *SD* below the national ICSEA value. As such our findings do not have the range or power in the lower range to detect any gene-environment interactions that might address very disadvantaged schools in Australia. Our upper SES distribution more closely aligns with the population, as such our results speak most closely to the effects in the normal to advantaged range of environments in Australia.

Although parent education has frequently been employed as a measure of family SES, we acknowledge that SES is a complex construct, and perhaps aspects of SES that are independent from parent education may moderate the heritability of literacy and numeracy, as noted by Harden et al. (2007).

A broader limitation in assessing the influence of SES on literacy and numeracy, either as a main effect or as a moderator of genetic and environmental influences, is that SES is a distal construct. Future studies could seek to measure the specific processes that mediate the effect of SES on literacy and numeracy. These processes might be genetic or environmental in origin. They might be motivational factors, as explored by Tucker-Drob and Harden (2012a, 2012b), or they might be access to specific resources, like health care and quality of education.

Another limitation is our inability to estimate the presence, or extent, of assortative mating on performance in literacy and numeracy. The parents in this study correlated on their level of education, which has been shown to account for the shared environmental variance in twin level of education (Baker, Treloar, Reynolds, Heath, & Martin, 1996). Without access to parent performance on the literacy and numeracy measures, we are unable to assess the degree of assortative mating in these data. Rather we acknowledge that the shared environmental estimates may be overestimated.

Conclusions

The main finding of the current study was that the influence of genes and the environment on performance in literacy and numeracy tests in Australia are largely the same across different levels of SES. In particular, genetic effects are substantial and stable regardless of whether parents did not complete high school or have post-doctoral degrees and regardless of whether children attended school with an ICSEA value of 900 or 1,200. Although family SES contributes 7%–10% and school SES contributes a further 1%–5%, more than half of variation in NAPLAN performance is due to inherited child characteristics independent of both family and school SES. The absence of constrained genetic effects on literacy and numeracy in Australia is encouraging for a society that aims to provide quality education regardless of the school attended, although it remains for the main effect of SES on literacy and numeracy performance to be reduced.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Sex-Limitation Model Fit Comparisons for Literacy in Grades 3, 5, 7, and 9