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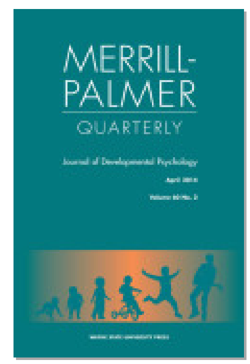

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A Quantitative Genetic Analysis of the Associations Among Language Skills, Peer Interactions, and Behavioral Problems in Childhood: Results From a Sample of Twins

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A body of empirical research has revealed that there are associations among language skills, peer interactions, and behavioral problems in childhood. At the same time, however, there has been comparatively less research devoted to exploring the mutual unfolding of these factors over the first few years of life. The current study is designed to partially address this gap in the literature by examining how language skills, negative peer interactions, and behavioral problems are interrelated in a sample of twins drawn from the Early Childhood Longitudinal Study–Birth Cohort (ECLS-B). Employing a quantitative genetic framework, the results of the current study revealed that variance in language skills, negative peer interactions, and externalizing behavioral problems were all due to a combination of genetic and environmental factors. Bivariate Cholesky models indicated that most of the covariance among language skills, negative peer interactions, and externalizing behavioral problems was due to common genetic factors. Additional analyses using a modified DeFries–Fulker approach

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nested within a path model revealed a bidirectional association between negative peer interactions and externalizing behavioral problems, wherein there appeared to be feedback loops between the two. Implications of the results are discussed and avenues for future research are offered.

The emergence of language in childhood signifies one of the quintessential developmental milestones during the first few years of life. With the development of language, children are able to communicate their needs, their wants, and anything else without relying purely on nonverbal forms of communication. Although all healthy children eventually acquire language skills, there is a tremendous amount of variation regarding the age at which the onset of language occurs, the growth in language skills, and the breadth of words in their vocabulary repertoire (Hart & Risley, 1995). Much of the variation in childhood tends to level off later in life, but, importantly, children who score near the bottom in language skills tend to lag behind others across many important developmental measures (Clegg, Hollis, Mawhood, & Rutter, 2005). Just as important, however, is that scoring low on measures of language abilities during childhood has been found to predict a wide variety of phenotypic outcomes later in life.

Of all the outcomes associated with reduced language skills, some of the most consistent evidence has been found in relation to antisocial behaviors and risk factors for antisocial behaviors (Yew & O'Kearney, 2013). Deficits in language skills, for example, have been linked to an increased risk of developing attention-deficit/hyperactivity disorder (ADHD) (Willcutt, Pennington, & DeFries, 2000), problems with interpreting emotional cues correctly (Cohen et al., 1998), school failure (Dworkin, 1989; Lloyd, 1978), behavioral problems (Gallagher, 1999), serious forms of childhood aggression (Dionne, Tremblay, Boivin, Laplante, & Pérusse, 2003), and reduced levels of self-control and self-regulation (Beaver, DeLisi, Vaughn, Wright, & Boutwell, 2008; Fujiki, Brinton, & Clarke, 2002; Vallotton & Ayoub, 2011). The comorbidity between poor language development and emotional and behavioral problems later in life has been consistently reported across studies examining a wide variety of samples and employing various measurement techniques (Benner, Nelson, & Epstein, 2002; Long, Gurka, & Blackman, 2008; Vallotton & Ayoub, 2011). Indeed, a recent meta-analysis reported significantly greater prevalence of behavioral and emotional problems in children evincing language problems relative to children with typical language development (Yew & O'Kearney, 2013).

In addition, poor language skills in childhood have consistently been found to predict more serious types of delinquent and criminal behaviors during adolescence and adulthood. To illustrate, a study evaluating language development and communication skills among a sample of juvenile offenders found that 66%–90% of juveniles had below-average language development, and 62% of the sample did not score high enough to achieve their age-equivalence literacy level (Bryan, Freer, & Furlong, 2007). Evidence of an inverse association between language skills and delinquent behavior has also been found to cut across adolescent male (Snow & Powell, 2008) and female (Sanger, Hux, & Belau, 1997) samples. Perhaps the most convincing evidence tying language skills to criminal behavior comes from a study conducted by Stattin and Klackenberg-Larsson (1993) in which language skills at the ages of 6, 18, and 24 months were significant predictors of the number of arrests during adulthood. The findings from available studies converge to show that there is a statistically significant and robust association between reduced language skills and various forms of antisocial behaviors at different points in the life course.

Given that antisocial behavior often remains stable from childhood through adulthood, a complete understanding of the link between reduced language skills in childhood and antisocial behavior in adulthood must focus on understanding the mutual unfolding of language skills and behavioral problems during childhood. To this point, however, not much research has attempted to identify the mechanisms that might account for the nexus between language skills and behavioral patterns early in the life course. Even so, at least two different processes that could be involved in creating the association between language and behavior can be identified: (a) an indirect causal effect explanation and (b) a spurious explanation. Both explanations are reviewed in this article.

Indirect Causal Effect Explanation

The first explanation for the link between language skills and antisocial behavior is referred to as the *indirect causal effect explanation.* According to this logic, language skills have a causal effect on antisocial behaviors, but instead of having a direct effect, they are mediated by another factor or set of factors. Trying to identify all of the factors that might mediate the effects of language skills on behavioral problems in childhood is nearly impossible, but the existing empirical literature provides a clue to one of the more salient factors likely to mediate this association. A body of research has revealed, for instance, that language skills are related to the ability to forge and sustain complex social relationships, especially with same-aged peers (Brinton & Fujiki, 1993; Caplan, Vespo, Pedersen, & Hay, 1991; Hay, Payne, & Chadwick, 2004; McCabe, 2005). To illustrate, McCabe (2005) reported that preschoolers with language impairments were less likely to have adequate peer social skills than were children with other types of impairments and children with normal language development.

In order for peer groups to mediate the effects of language skills on childhood behavioral problems, differential exposure to negative peer interactions has to be related, in some capacity, to antisocial behaviors. Findings from a wide range of studies provide strong evidence that negative peer interactions and exposure to antisocial peer groups are associated with an increased probability of displaying serious signs of childhood antisocial behavior, as well as delinquent and criminal involvement later in life (Farrington, 2005; Harris, 1995, 1998; Patterson, Capaldi, & Bank, 1989; Warr, 2002). For example, a number of studies that have analyzed samples of young children have shown that one of the best predictors of serious forms of childhood antisocial behavior is a lack of supportive and strong positive peer relationships (Farrington, 2005; Hay et al., 2004). These effects have been found to persist beyond childhood, wherein children who lack prosocial friendship groups are more likely to engage in delinquency and antisocial behaviors in adolescence (Cairns & Cairns, 1994; Quinton, Pickles, Maughan, & Rutter, 1993).

Peer relationships are integral to normal healthy development throughout all stages of the life course but are perhaps most salient in childhood (Deater-Deckard, 2001; Rubin, Bukowski, & Parker, 1998). Children who are unable to develop strong friendship ties may be set on an antisocial pathway that they follow throughout the rest of their life. While a complex arrangement of factors are likely at play in explaining how and why certain children experience deficits at forging positive peer relationships, there is good reason to believe that at least part of this variability is structured by language skills. The true extent to which peer relationships might mediate the language skills–behavioral problems nexus, however, remains relatively unknown.

Spurious Explanation

The second explanation for the association between language skills and antisocial behavior is that the association is purely *spurious.* According to this point of view, the link between reduced language skills and increased involvement in antisocial behavior is not the result of an indirect causal pathway but rather reflects a spurious association that is driven by confounding factors. If these potential confounding factors are identified and included in statistical models, then the association between language skills and antisocial behavior would no longer exist. One of the difficulties with assessing the spurious explanation is determining which variables—omitted from previous studies—might be confounding the association between language skills and antisocial behaviors. While virtually any omitted variable that is related to both language skills and antisocial behavior could confound the association, there is not a lot of evidence identifying factors that might affect both language development and antisocial behaviors. Some evidence is consistent, however, with the possibility that genetic factors might confound the link between language skills and antisocial behaviors.

A number of published studies have used methodologies capable of estimating genetic, shared environmental, and nonshared environmental influences on measures of language skills and on various measures of antisocial behaviors. Even though a wide range of heterogeneous samples have been examined and a variety of measures have been analyzed, the results flowing from these studies have been remarkably consistent. The available evidence suggests that, depending on the measure used, 25%–75% of the variance in language skills is explained by genetic factors (for a review, see Stromswold, 2001). Similar estimates have been reported for antisocial behavior at different stages of the life course (Ferguson, 2010; Mason & Frick, 1994; Miles & Carey, 1997; Moffitt, 2005; Raine, 1993; Rhee & Waldman, 2002), including childhood behavioral problems (Brendgen et al., 2005; Van Lier et al., 2007).

Although language skills and behavioral problems have both been found to be influenced by genetic factors, such a finding does not mean that the genetic influences that account for variation in language skills are the same genetic factors that account for variation in behavioral problems. At a minimum, for genes to be confounders in this association, the etiology of both language skills and behavioral problems must be the result of at least some of the same genetic factors. If the two are influenced by separate genetic factors, then genes would not confound this association. A limited amount of research has found some evidence consistent with the spuriousness argument. Specifically, Beaver et al. (2008) calculated a bivariate Cholesky decomposition model between language skills and levels of self-control in a sample of twin children drawn from the Early Childhood Longitudinal Survey–Kindergarten Class (ECLS-K). The results of their analyses revealed that 61%–76% of the covariance between language skills and low self-control resulted from shared genetic influences, suggesting that genes might confound the association between language skills and antisocial outcomes. Even after controlling for genetic influences, however, reduced language skills were still significantly associated with levels of self-control, a finding that is consistent with a causal effect explanation. Based on this study, there is some evidence in favor of the potential role of genes as confounders, but there is also evidence that genetic factors are unable to confound the entire association between language skills and antisocial outcomes.

In perhaps the most methodologically sound study to date to examine these different explanations, Dionne et al. (2003) examined the association between expressive vocabulary and physical aggression in a sample of 19-month-old twins. The results of their analysis revealed a statistically significant, though modest, association between physical aggression and vocabulary skills. Additional analyses revealed that the two were associated not because of a common etiology that would be in line with the spuriousness explanation but rather because of the effects that expressive vocabulary had on physical aggression. These findings provide some of the strongest evidence suggesting that expressive vocabulary has a significant influence on physical aggression even after controlling for genetic influences.

The Current Study

The current study is designed to examine the interrelationships among language skills, negative peer interactions, and externalizing behavioral problems in childhood. Both of the two explanations already discussed will be tested. However, it should be noted that these explanations are not necessarily mutually exclusive and that variants of each will be explored. For example, the inherent assumption in the explanations is that behavioral problems represent the ultimate endogenous variable. Some research indicates, however, that there might be reciprocal effects and feedback loops between behavioral problems and negative peer interactions (Farrington, 2005; Harris, 1998; Patterson et al., 1989; Warr, 2002). As a result, the statistical models will address these alternative explanations, as well. All of the statistical models testing these explanations will employ a quantitative genetic approach as a way to take into account the role that genetic factors have on language skills (Pinker, 1994; Stromswold, 2001), peer interactions (Beaver et al., 2009; Cleveland, Wiebe, & Rowe, 2005; Iervolino et al., 2002), and antisocial behaviors (Ferguson, 2010; Mason & Frick, 1994; Miles & Carey, 1997; Rhee & Waldman, 2002). To do so, a sample of twin pairs drawn from one of the largest prospective samples of American children will be analyzed.

Methods

Data

Data for this study come from the Early Childhood Longitudinal Study–Birth Cohort (ECLS-B), which is a prospective, longitudinal, and nationally representative sample of American children born in 2001. The National Center for Health Statistics provided a list of all U.S. birth certificates (estimates indicate that 99% of all births are registered with the NCHS), and stratified sampling techniques were employed to draw the sample from this list. Children were removed from this list if they met any of these three following: (a) their mothers were younger than age 15 at the time of birth, (b) they died before 9 months of age, or (c) they were adopted before 9 months of age. Approximately 14,000 children were selected for inclusion in the ECLS-B. Note that to comply with the user agreements of the ECLS-B data, all sample sizes have been rounded to the nearest 50. Information about the children has been collected from multiple reporting sources, including their mothers, their fathers, their primary caregivers, and independent raters, as well as through standardized testing procedures and data contained on their birth certificates (Bethel, Green, Nord, Kalton, & West, 2005).

The initial wave of data was collected between 2001 and 2002 when the children were 9 months old. During this wave of data collection, the primary caregiver (usually the mother) was asked an extensive number of questions about their child, their living arrangements, and their background characteristics. Fathers were also administered a survey and asked a series of questions pertaining to their child, their partner (e.g., spouse), and themselves. Independent rater observations were also used to measure parent–child relations and aspects of the child's development. In total, 10,700 families participated in the Wave 1 component of the ECLS-B (Bethel et al., 2005; Nord, Edwards, Andreassen, Green, & Wallner-Allen, 2006).

The second wave of data was collected between 2003 and 2004 when the children were 2 years of age. The questions mothers and fathers were asked at Wave 1 were very similar to the questions asked at Wave 2. For example, they were asked to report on the child's developmental milestones, their parenting practices, and their living conditions. Independent raters were once again used to complete standardized assessment instruments about the child's development. Given that a relatively high proportion of the children spent considerable time under the supervision of primary caregivers other than their parents, every effort was made to interview other primary caregivers, typically a professional day-care provider. A total of 9,850 families participated in the Wave 2 data of the ECLS-B (Bethel et al., 2005; Nord et al., 2006).

The third wave of data was collected between 2005 and 2006 when the children were approximately 4 years old. The interview instruments were altered to include questions that were reliable and valid measures of topics germane to 4-year-olds. For instance, parents and preschool teachers were asked to report about the child's behavioral problems and the child's ability to forge and maintain friendships. Psychometric tests were administered by a trained professional to measure the child's fine and gross motor skills. During Wave 3 interviews, children also completed standardized tests designed to measure their cognitive skills related to language development and mathematics. A total of 8,950 families were successfully reinterviewed at Wave 3 (Bethel et al., 2005; Nord et al., 2004).

One of the unique features of the ECLS-B data is that twins were oversampled for inclusion in the sample, which resulted in more than 800 twin pairs. The zygosity of same-sex twin pairs was determined through parental and interviewer reports. Parents, for instance, were asked to indicate the blood type of each twin and were also asked a series of questions related to the similarity of the twins (e.g., eye color, hair texture, the shape of their ear lobes). These items have been shown to be highly valid and reliable in correctly classifying twins as either monozygotic (MZ) or dizygotic (DZ) twin pairs (Cohen, Dibble, Grawe, & Pollin, 1975; Goldsmith, 1991; Nichols & Bilbro, 1966). After removing twins whose zygosity was unknown, the final analytic sample size employed in the current study consisted of nearly 500 same-sex twin pairs ($n = 100$ MZ twin pairs, and $n = 400$ same-sex DZ twin pairs). Table 1 lists the descriptive statistics for the scales and variables used in the analyses, and Table 2 contains a correlation matrix for all of the variables and scales.

Measures

Externalizing behavioral problems. During Wave 3 interviews, parents were asked eight questions designed to measure their child's externalizing behavioral problems. Teacher ratings of the child's externalizing behavioral

Table 1. Descriptive statistics for the ECLS-B sample variables ($N =$ ~500 twin pairs)

	M	*SD*	Min.–max.	% Missing
Externalizing behavioral problems	19.60	5.07	8–40	7.4
Negative peer interactions	21.54	5.79	12–41	8.2
Language skills	24.88	12.10	0–50	1.4

Note. ECLS-B = Early Childhood Longitudinal Study–Birth Cohort.

Table 2. Correlation matrix for selected ECLS-B variables and scales (N = ~500 twin pairs)

		X1	X2	X3
Externalizing behavioral problems	X1	1.00		
Negative peer interactions	X2	.29*	1.00	
Language skills	X3	−.12*	−.25*	1.00

Note. ECLS-B = Early Childhood Longitudinal Study–Birth Cohort.

*$p < .05$, two-tailed tests.

problems were also available but were not used because of the large percentage of missing data. Data were missing primarily because some children had not been enrolled in preschool and/or had not been supervised by a day-care provider. The same was true for the Negative Peer Interactions Scale. As a result, only the parental ratings were included in the construction of these two scales. These items, drawn from the Preschool and Kindergarten Behavior Scales–Second Edition (PKBS-2; Merrell, 2002), indexed various problem behaviors, including whether the child is aggressive, is impulsive, is overactive, throws temper tantrums, has difficulty concentrating, annoys others, and destroys things. Responses to these items were coded such that higher values indicated more behavioral problems (1 = *never,* 2 = *rarely,* 3 = *sometimes,* 4 = *often,* and 5 = *very often*). Factor analysis confirmed that these eight items loaded on a single underlying factor, and internal reliability assessment indicated that removing any of the items would not increase Cronbach's alpha coefficient. As a result, these eight items were summed to create the Externalizing Behavioral Problems Scale ($\alpha = .80$).

Negative peer interactions. During Wave 3 interviews, parents were asked eight questions that indexed their child's ability to interact with peers and sustain friendships. These items, also drawn from the PKBS-2, were designed to measure various dimensions of peer interactions, such as whether the child is liked by their peers, shares with others, understands other children, makes new friends easily, is invited to play by other children, volunteers to help others, and comforts other children. The response set for these questions was 1 = *never,* 2 = *rarely,* 3 = *sometimes,* 4 = *often,* and 5 = *very often.* Factor analysis revealed that these items loaded on a single factor. Internal reliability assessment indicated that removing any of the items would not significantly increase Cronbach's alpha coefficient. After reverse coding certain questions, responses to the eight items were summed to create the Negative Peer Interactions Scale ($\alpha = .82$). Higher values on this scale reflect more problems interacting with peers.

Language skills. During Wave 2 interviews, parents were asked to report about their child's language skills. More specifically, they were presented with a list of 50 words and asked which, if any, their child could speak. For instance, included on the list were words such as meow, shoe, fast, duck, mop, and rip. Words that the child could speak were coded as 1, and words that the child could not speak were coded as 0. These dichotomous responses were summed to create a Language Skills Scale, where the value on the scale indicated the total number of words (out of 50) that the child could speak ($\alpha = .95$). To check the validity of this scale, we correlated it with five items measuring verbal skills from the Wave 2 Bayley Short Form, including receptive vocabulary skills, expressive vocabulary scores, the ability to name objects, the ability to jabber expressively, and listening/comprehension scores. The correlations between the Language Skills Scale and these items were all statistically significant, and the Pearson correlation coefficients ranged from $r = .373$ to $r = .606$ (all ps $< .001$). In addition, a composite scale was created by summing these five items. The correlation between the composite score and the language skills score was $r = .603$ ($p < .001$).

Plan of Analysis

The analysis for this study proceeded in three linked steps. First, univariate variance component models were calculated separately for the Externalizing Behavioral Problems Scale, the Negative Peer Interactions Scale, and the Language Skills Scale by using the statistical program M*plus*. The univariate variance component models compare correlations within twin dyads across different levels of genetic relatedness to provide an estimate of the proportion of total variance explained by genetic (symbolized as A) and environmental influences. Importantly, this modeling technique further partitions the variance explained by the environment into two categories: shared and nonshared environmental influences. Shared environmental influences (symbolized as C) are comprised of environmental factors that make twins from the same dyad more alike, whereas nonshared environmental influences (symbolized as E) are environmental factors that make each twin within a given dyad different from the other.

Second, we estimated bivariate Cholesky decomposition models to decompose the covariance between language skills and negative peer interactions, language skills and externalizing behavioral problems, and negative peer interactions and externalizing behavioral problems. This modeling strategy allows for the decomposition of the covariance between the two examined measures into the A, C, and E parameters. Similar to the univariate variance component models, the A parameter provides an estimation of the proportion of the covariance between the two measures that is explained by common genetic influences. The C parameter would indicate the amount of covariance that can be explained by common shared environmental factors, and the E parameter would indicate the amount of covariance that can be explained by common nonshared environmental influences. The results of these models bear on the spuriousness explanation, wherein if a significant amount of the covariance is found between language skills and the two antisocial phenotypes, then the association between the two might not be indirect (i.e., from phenotype to phenotype) but due to a shared etiology.

Third, we examined the reciprocal effects between negative peer interactions and externalizing behavioral problems by employing a unique application of DeFries–Fulker (DF) analysis (DeFries & Fulker, 1985). *DF analysis* is a regression-based statistical technique designed to be used with samples of kinship pairs. The parameters generated from DF analysis provide direct estimates of A and C, while E is calculated by summing A and C and subtracting that total from 1. Although the original DF equation was advanced to be used with samples where one twin had an extreme score on a particular measure, the DF equation has since been modified and transformed so it can be employed with samples drawn from a nonclinical population (Rodgers & Kohler, 2005; Rodgers, Rowe, & Li, 1994). The baseline DF equation takes the following form:

$$K_1 = b_0 + b_1K_2 + b_2R + b_3(R * K_2) + e \tag{1}$$

where K_1 is the score for one twin on the scale being analyzed, K_2 is their co-twin's score on that same scale, R measures genetic similarity ($R = 1.0$ for MZ twins, and $R = .5$ for DZ twins), and $R * K_2$ is an interaction term created by multiplying R and K_2. In this equation, b_0 = the constant, b_1 = the proportion of variance in the scale that is explained by shared environmental influences, b_2 is not typically interpreted in the DF model, and b_3 = the proportion of variance in the scale that is accounted for by genetic factors. The proportion of variance in the scale that is accounted for by the nonshared environment (plus error) is captured by the error term, e.

The DF equation just presented was host to a number of shortcomings that were addressed by Rodgers and Kohler (2005), who advanced a modified DF equation to overcome these problems. The new DF equation takes this form:

$$K_1 = b_0 + b_1(K_2 - K_m) + b_2(R * [K_2 - K_m]) + e \quad (2)$$

where K_1 remains the score on the scale for one twin, K_2 remains the co-twin's score on that same scale, and R remains a measure of genetic similarity. The main difference between Equation 1 and Equation 2 is that Equation 2 includes a new term, K_m. In this DF equation, K_m = the mean of the scale of interest (i.e., the mean for K_2). This DF equation also shows that K_2 is being mean centered, whereas the main effect of R is removed. The interpretation of the coefficients, however, does not change between Equation 1 and Equation 2. Indeed, b_1 = the proportion of the scale's variance that is the result of shared environmental effects, and b_2 = the proportion of the scale's variance that is attributable to genetic effects, whereas e = the proportion of the scale's variance that is accounted for by nonshared environmental effects and error. Equation 2 was used to estimate the variance components for the Externalizing Behavioral Problems Scale, the Negative Peer Interactions Scale, and the Language Skills Scale.

The DF models presented in Equation 2 can be nested within a path analysis to examine interrelationships among language skills, negative peer interactions, and externalizing behavioral problems in a longitudinal genetic framework. To understand this analytic strategy, Figure 1 was constructed to show a schematic depiction of the DF model nested within a path analysis. Three points warrant further discussion. First, heritability and shared environmental effects were estimated for the Language Skills Scale, the Negative Peer Interactions Scale, and the Externalizing Behavioral Problems Scale. These parameters were estimated with Equation 2, where b_1 from the equation = the shared environmental effect, and b_2 = heritability. Essentially, Equation 2 was estimated for each of these three scales, but instead of estimating them separately with a series of ordinary least squares (OLS) equations, they were calculated simultaneously in a path model.

Second, the variance not accounted for by heritability and shared environmental effects was attributable to the nonshared environment (plus error). The nonshared environmental terms are represented as unobservables in Figure 1 and thus are depicted in standard structural equal model notation as circles (labeled e_1, e_2, and e_3). In other words, after the DF equation was estimated, the residual variance was used as a measure of the nonshared environment because the similarity between twins is accounted for by heritability and shared environmental influences.

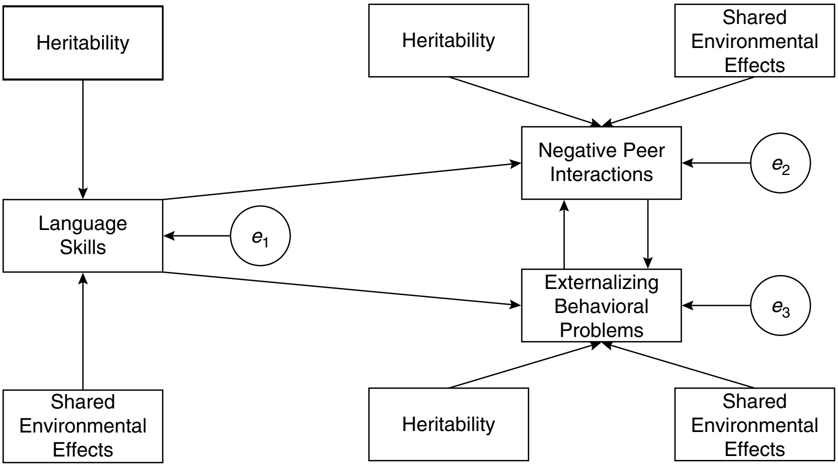

Figure 1. The estimated DeFries–Fulker model nested within path analysis. The non-shared environmental effects are captured by the error terms (labeled e_1, e_2, and e_3).

Third, this DF model estimates reciprocal effects between the Negative Peer Interactions Scale and the Externalizing Behavioral Problems Scale. By including reciprocal effects, it is possible to begin to estimate whether the association between peer interactions and behavior is due to negative peer interactions impacting externalizing behavioral problems, externalizing behavioral problems impacting negative peer interactions, or some combination of these two processes.

All of the DF models were estimated by using the structural equation modeling statistical software package, AMOS (Analysis of Moment Structures; SPSS, Chicago). AMOS employs a full-information maximum likelihood (FIML) imputation algorithm to estimate values for missing data. As a direct result, the DF models were based on the full sample of MZ and same-sex DZ twins (N = ~500 twin pairs). Importantly, the DF models were estimated by using single-entry procedures where one twin was randomly selected to be used as the dependent variable and the other was used as the independent variable.

Results

The analysis began by estimating the variance components for the Externalizing Behavioral Problems Scale, the Negative Peer Interactions Scale, and the Language Skills Scale. Recall that these models were estimated by using univariate variance component models. Models were estimated successively from the full ACE (*a*dditive genetic factor, *c*ommon environment, unique *e*nvironment) model to subsequently restrictive models. Various model-fit statistics were used to determine which model best fit the data. Specifically, the Wald's test of parameter constraints, the Akaike's information criterion (AIC), the Bayesian information criterion (BIC), and the root mean square error of approximation (RMSEA) were estimated to assess model fit. Table 3 reveals the results of these models. The best-fitting model for the Externalizing Behavioral Problems Scale was an AE model where genetic factors accounted for 72% of the variance and nonshared environmental factors explained the remaining 28%. A very similar pattern of results was observed for the Negative Peer Interactions Scale, where genetic factors explained 74% of the variance and nonshared environmental factors accounted for the remaining 26%. For the Language Skills Scale, genetic factors explained 34% of the variance, whereas the shared environment accounted for 63%. The nonshared environment explained only 4% of the variance in language skills.

The next step in the analysis, presented in Table 4, involved the estimation of bivariate Cholesky decomposition models to decompose the covariance between language skills and negative peer interactions, language skills and externalizing behavioral problems, and negative peer interactions and externalizing behavioral problems. Model-fit statistics (i.e., AIC, BIC, and RMSEA) were used to identify the model that best fit the data. The results of the first model indicated that 100% of the covariance between the externalizing behavioral problems measure and the language skills measure was explained by genetic influences. The results of the second model indicated that genetic factors explain 71% of the covariance between externalizing behavioral problems and negative peer interactions, whereas nonshared environmental influences explain the remaining 29%. Finally, 100% of the covariance between language skills and negative peer interactions was explained by genetic influences.

The analyses thus far indicate significant genetic influences on all of the measures of interest. Moreover, genetic factors explained all of the associations of language skills with negative peer interactions and externalizing problems, respectively, but only part of the association between negative peer interactions and externalizing problems. As a result, what remains unknown is the direction of the association between negative peer interactions and externalizing behavioral problems. To address this issue, the path model presented in Figure 1 was estimated wherein reciprocal effects were directly modeled between negative peer interactions

Table 3. Univariate variance components estimates (N = ~500 twin pairs)

	A	C	E	χ^2	$\Delta\chi^2$	AIC	BIC	RMSEA
Externalizing behavior problems								
ACE	.62**	.09	.29**	6.767		5,313.612	5,330.067	.02
	[.43, .81]	[−.07, .24]	[.22, .36]					
AE	.72**	.00	.28**	7.639	.896	5,312.484	5,324.825	.02
	[.66, .78]	[.00, .00]	[.22, .34]					
CE	.00	.46**	.54**	26.005**	28.419**	5,330.850	5,343.191	.11*
	[.00, .00]	[.40, .53]	[.48, .60]					
E	.00	.00	1.00**	135.063**	333.818**	5,437.908	5,446.136	.27**
	[.00, .00]	[.00, .00]	[1.00, 1.00]					
Negative peer interactions								
ACE	.63**	.10	.27**	7.177		5,129.553	5,145.999	.03
	[.45, .81]	[−.05, .25]	[.21, .33]					
AE	.74**	.00	.26**	8.379	1.252	5,128.754	5,141.089	.03
	[.69, .80]	[.00, .00]	[.20, .31]					
CE	.00	.49**	.52**	21.874**	32.024**	5,149.177	5,161.512	.10*
	[.00, .00]	[.42, .55]	[.45, .58]					

E	.00	.00	1.00**	148.051**	405.310**	5,266.426	5,274.649	.28**
	[.00, .00]	[.00, .00]	[1.00, 1.00]					
Language skills								
ACE	.34**	.63**	.04**	4.371		6,901.825	6,918.561	.00
	[.28, .40]	[.57, .68]	[.03, .05]					
AE	.96**	.00	.04	115.576**	297.672**	7,011.029	7,023.582	.25**
	[.95, .97]	[.00, .00]	[.03, .05]					
CE	.00	.84**	.17**	97.472**	88.028**	6,992.925	7,005.478	.23**
	[.00, .00]	[.81, .86]	[.14, .19]					
E	.00	.00	1.00**	666.995**	33,542.372**	7,560.448	7,568.817	.58**
	[.00, .00]	[.00, .00]	[1.00, 1.00]					

Note. The 95% confidence intervals are in brackets. The best-fitting model is in bold. ACE = *a*dditive genetic factor, *c*ommon environment, unique *e*nvironment; AIC = Akaike information criterion; BIC = Bayesian information criterion; RMSEA = root mean square error of approximation.

$^{**}p < .01$.

$^{*}p < .05$.

Table 4. Bivariate Cholesky variance components estimates ($N = \sim500$ twin pairs)

	A	C	E	χ^2	AIC	BIC	.
Externalizing behavior problems/language skills	1.00**	.00	.00	131.856**	12,305.100	12,334.418	.147**
	[1.00, 1.00]	[.00, .00]	[.00, .00]				
Externalizing behavior problems/negative peer interactions	.71**	.00	.29**	16.506	10,384.403	10,421.426	.000
	[.54, .88]	[.00, .00]	[.12, .47]				
Language skills/negative peer interactions	1.00**	.00	.00	136.033**	12,806.526	12,115.843	.150**
	[1.00, 1.00]	[.00, .00]	[.00, .00]				

Note. The 95% confidence intervals are in brackets. AIC = Akaike information criterion; BIC = Bayesian information criterion; RMSEA = root mean square error of approximation.

**$p < .01$.

*$p < .05$.

†$p < .10$.

and externalizing behavioral problems ($\chi^2 = 6659.16$, $df = 25$, $p < .05$; RMSEA = .522, $p < .05$). Although they are not shown, shared environment parameters (i.e., b_1 from Equation 3) and heritability parameters (i.e., b_2 from Equation 3) are estimated on each variable. (The substantive results were identical when the shared environment [b_1] was fixed to 0.00 for externalizing behavioral problems and negative peer interactions to be consistent with the ACE results in Table 3.) The standardized parameter estimates presented in Figure 2 provide evidence that is consistent with a feedback effect, where negative peer interactions were positively associated with externalizing behavioral problems, and where externalizing behavioral problems were positively associated with negative peer interactions. In short, those who scored higher on the Negative Peer Interactions Scale, on average, scored higher on the Externalizing Behavioral Problems Scale. Model-fit statistics were calculated to examine how the reciprocal effects model fit the data. Model chi-square estimates and AIC revealed that the reciprocal effects model was a better fit to the data than were the baseline model and a unidirectional effects model.

It is important to note that reciprocal effects models require the researcher to make additional assumptions. When these assumptions are not met, the parameters in the reciprocal part of the model can become unstable (Wooldridge, 2009). In an effort to gauge the robustness of the findings, we estimated a series of alternative models that relaxed certain assumptions. Additionally, we estimated these sensitivity models with listwise deletion in Stata 12.1 (StataCorp, College Station, TX). For instance, we estimated an alternative version of the model presented in Figure 2 by omitting the language skills variable, omitting the shared environment parameters per the ACE model results in Table 3, correlating the error terms between the endogenous variables (i.e., externalizing behavioral problems and negative peer interactions) to account for sources of omitted covariance, such as shared methods variance, and correlating the heritability estimates between the endogenous variables to account for the shared genetic covariance highlighted by the Cholesky models in Table 4. When these steps were used, neither path in the reciprocal part of the model was statistically significant, but the substantive findings suggested that externalizing behavioral problems influence negative peer interactions ($\beta = .13$, $z = 1.42$), whereas negative peer interactions have a negligible impact on externalizing behavioral problems ($\beta = -.02$, $z = -.21$). Given the sensitivity of these results, we encourage readers to be cautious when interpreting the findings from the reciprocal models.

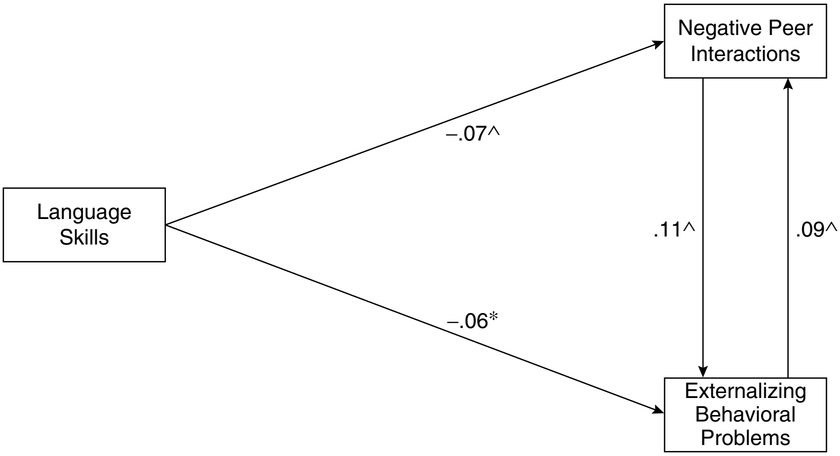

Figure 2. Modeling the reciprocal relationship between negative peer interactions and aggression externalizing behavioral problems in a sample of twin pairs (N = ~500). *$p < .05$, two-tailed tests. ^$p < .10$, two-tailed tests. Standardized coefficients are presented.

Discussion

The onset of serious antisocial behavior early in the life course represents one of the best predictors of future criminal and delinquent involvement, with virtually all lifelong career criminals having a history of behavioral problems that dates back to childhood (Robins, 1978). As a result, one of the most effective ways to prevent offending behaviors in adolescence and adulthood is by blunting the emergence in childhood of risk factors known to contribute to antisocial behaviors. The efficacy of such a prevention-based approach, however, hinges on the capacity (a) to identify risk factors that are causally related to antisocial behaviors and (b) to examine the interrelationships among the risk factors systematically in order to explicate the underlying processes ultimately responsible for contributing to the development of antisocial behaviors. The current study was designed to take a cautious step in this direction by examining the associations among language development, peer interactions, and externalizing behavioral problems in a sample of twin children. Findings from three main sets of analyses formed the backbone of the current study.

First, univariate variance decomposition models were conducted to estimate the extent to which variance in externalizing behavioral problems, negative peer interactions, and language skills was explained by genetic, shared environmental, and nonshared environmental factors. The estimates generated from these analyses indicated that 72% of the variance in externalizing behavioral problems was due to genetic factors, none of the variance was attributable to shared environmental factors, and 28% of the variance was explained by nonshared environmental factors. Similar estimates were garnered for the Negative Peer Interactions Scale, wherein 74% of the variance was accounted for by genetic factors, none was accounted for by shared environmental factors, and 26% was accounted for by nonshared environmental factors. Last, 34% of the variance in language skills was attributable to genetic factors, 63% was attributable to shared environmental factors, and 4% of the variance was explained by nonshared environmental factors. These estimates are consistent with those from previous research revealing that genetic factors tend to be the dominant source of variance in behavioral problems and peer interactions (Beaver et al., 2009; Rhee & Waldman, 2002), whereas environmental factors are more salient for language abilities during early childhood (Petrill, Deater-Deckard, Thompson, De Thorne, & Schatschneider, 2006).

The second key set of findings emerged from the bivariate Cholesky decomposition models. The results garnered from these models suggest that genetic factors account for the vast majority of the covariance between the measures examined. More specifically, genetic factors account for all of the covariance between externalizing behavioral problems and language skills and between language skills and negative peer interactions. Although nonshared environmental influences did significantly explain some of the covariance between externalizing behavioral problems and negative peer interactions (29%), the covariance was largely explained by genetic factors (71%). Collectively, the results of the bivariate Cholesky decomposition models suggest that observed correlations between externalizing behavioral problems, negative peer interactions, and language skills are driven primarily by genetic influences.

The third, and perhaps most interesting, aspect of the analyses was the potential reciprocal effects between negative peer interactions and externalizing behavioral problems after controlling for common underlying genetic causes. A pool of research indicates that antisocial behaviors tend to have feedback loops on a range of environmental factors, including family dynamics and parent–child interactions (Boutwell, Franklin, Barnes, & Beaver, 2011; Jaffee et al., 2004; Moffitt, 2005; Taylor, Iacono, & McGue, 2000; Thapar et al., 2005). As a result, we explored whether there was a bidirectional association between negative peer interactions and externalizing behavioral problems when common underlying genetic causes were controlled. The results of this model revealed a bidirectional association wherein negative peer interactions were related to an increase in externalizing behavioral problems that, in turn, were related to an increase in negative peer interactions. These findings indicate that negative peer interactions and externalizing behavioral problems in childhood may be inextricably linked and that trying to isolate the effects of one on the other is likely misguided. Because of the sensitivity of these models, however, more research is needed to fully explore how these developmental outcomes unfold in a codependent fashion early in the life course.

While the results of the current study provide some insight into the interrelationships among language skills, negative peer interactions, and externalizing behavioral problems, a number of limitations need to be addressed in future studies. To begin with, the time lag between Waves 2 and 3 of data collection was only a few years. Given that phenotypes tend to be highly stable over time (Roberts & Del Vecchio, 2000; Stattin & Magnusson, 1996), it would have been better to examine a wider time range to determine whether the effects of language skills on peer interactions and externalizing behavioral problems would have persisted into late childhood or even early adolescence. Similarly, the Negative Peer Interactions Scale and the Externalizing Behavioral Problems Scale were both assessed only at Wave 3, making it impossible to establish temporal ordering between the two. Although we were able to partially explore the potential effects of peer interactions on externalizing behavioral problems (and vice versa) by using a reciprocal effects model, ideally the ECLS-B would have included the same measures at various data-collection waves. This would have enabled us to examine more fully which factor, if either, was antecedent to the other. Last, the three core scales used in this study—externalizing behavioral problems, negative peer interactions, and language skills—were reported on by parents. As a result, the intercorrelations among these scales may be artificially inflated by shared methods variance. Until these shortcomings are addressed in replication studies, the results of the current study should be viewed with caution.

As the results of the current study indicate, variation in language skills during childhood can set children on different developmental life-course trajectories. Reduced language skills in childhood, for example, may be an indicator of an antisocial trajectory that is marked by high levels of externalizing behavioral problems and high rates of negative peer interactions. This is particularly important for two reasons: First, antisocial behavior is highly stable over the life course. Children who begin to display antisocial behaviors in childhood, therefore, are at-risk for engaging in such behaviors into adolescence and even adulthood. Second, friendship networks represent one of the dominant socializing agents early in life (Harris, 1995, 1998; Hay et al., 2004) and become even more important in adolescence and adulthood. The dynamic interactions that unfold within peer groups may ultimately be responsible for life outcomes, behavioral patterns, and even the formation of personality traits (Harris, 1995, 1998; Ladd, 2005). Against this backdrop, continuing to unpack the interrelationships among language skills, peer relations, and behavioral problems may go a long way toward ultimately being able to prevent the emergence of long-term, chronic antisocial behavior among youth.

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