Biological and Psychosocial Factors Affect Linguistic and Cognitive Development Differently: A Twin Study

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Abstract. Although twin studies clearly demonstrate that genetic factors play an important role in language acquisition, some twin studies suggest that adverse prenatal (Koeppen-Schomerus et al., 2000) or postnatal (Turkheimer et al., 2003) environments can overshadow the effects of genetic factors. The current study investigates, in the same group of twins, the extent to which prenatal and postnatal environmental factors interact with genetic factors to affect linguistic and nonlinguistic development. The study included 145 sets of same-sex monozygotic twin pairs and 238 sets of same-sex dizygotic twin pairs. The twins' development was assessed using Bricker & Squire's (1999) Ages & Stages language, cognitive, gross motor, fine motor, and social tests. Twins were divided into two prenatal risk groups based on gestational age at birth (GA). Twins were also divided into two postnatal risk groups based on socioeconomic status (SES). Genetic factors accounted for 5 times more of the variance for high GA twins' language scores than for low GA twins' language scores, whereas genetic factors affected both GA groups' cognitive scores similarly. In striking contrast, for cognitive scores, genetic factors accounted for 3 times more of the variance for high SES twins than for low SES twins, whereas for language scores, genetic factors affected high and low SES twins virtually identically. Put simply, perinatal environment affects linguistic development and postnatal environment affects cognitive development. Because prenatal factors are overwhelming biological, whereas postnatal factors tend to be psychosocial, these results support nativist/biological theories of language acquisition and call into question empiricist/emergentist theories of language development.

1. Introduction

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The Logic of Twin Studies. The most common method used to tease apart the role of genetic and environmental factors in language development is to determine whether monozygotic (MZ) twins are linguistically more similar to one another than dizygotic (DZ) twins. Because MZ and DZ twins share essentially the same pre- and postnatal environments, whereas MZ twins share 100% of their alleles and DZ twins share only 50% of their alleles (but see Stromswold, 2001; Stromswold, to appear), if MZ twins are linguistically more similar to one another than DZ twins, this suggests that genetic factors play a role in language. Twin pairs are concordant for a language disorder if both twins are impaired, and discordant if only one twin is impaired. If the concordance rate for developmental language disorders is significantly greater for MZ than DZ twins, this suggests that genetic factors play a role in these disorders. If the data obtained are continuous, one can compare the similarity of MZ and DZ twins' linguistic abilities. The variability in linguistic abilities in a population is due to genetic and environmental factors. Using structural equation modeling (SEM), genetic factors can be divided into additive genetic factors (A) and dominant (D) genetic factors (Neale & Cardon, 1992). Environmental factors can be divided into environmental factors that twins do and do not share. Shared environmental factors (C) include the linguistic input twins receive (assuming parents speaks similarly to their twins), and non-shared environmental factors (E) include illnesses or accidents that only occur to one twin. Shared environmental factors contribute to twins' similarity and non-shared environmental factors contribute to twins' dissimilarity.

Genetic Factors and Language Development. Twin studies have clearly shown that genetic factors play a substantial role in children's language development. For example, meta-analyses of published twin studies reveal that genetic factors account for about 70% of spoken developmental language disorders, and between one half to two-thirds of the variability in language-impaired twins' language and between one-quarter to one-half of the variability in typically-developing (henceforth, normal) twins' language (Stromswold, 2001). These meta-analyses also reveal that for both language-impaired and normal twins, genetic factors play a greater role for phonological and syntactic abilities than for lexical abilities. These results are consistent with initial results from Stromswold et al.'s (2005) Perinatal Environment and Genetic Interactions (PEGI) twin study. Concordance analyses reveal that genetic factors account for over 80% of the language disorders in the PEGI twins. In addition, SEM reveals that genetic factors account for more of the linguistic variance for language-impaired PEGI twins than for normal PEGI twins. For example, dominant genetic factors only play a role in the linguistic abilities of language-impaired twins. That said, for both language-impaired and normal PEGI twins, genetic factors account for more of the variance for phonology (70% for language-impaired and 31% for normal twins) and syntax (100% for language-impaired and 26% for normal twins) than for vocabulary (69% for language-impaired and 5% for normal twins). Collapsing across language impaired and normal PEGI twins, additive and dominant genetic factors account for 68% of PEGI twins' phonological abilities, 59% of PEGI twins' syntactic abilities, and 40% of PEGI twins' lexical abilities.

Environment Factors and Language Development. Twin studies have also shown that environment factors play a substantial role in children' language development. For example, meta-analyses reveal that 30% of language impairments are due to environmental factors, and between one-third to one-half of language-impaired twins' linguistic abilities and between one-half to three-quarters of normal twins' linguistic abilities are due to environmental factors, with these factors playing a greater role for lexical abilities than phonological or syntactic abilities (Stromswold, 2001). Concordance analyses of the PEGI twins reveal that environmental factors account for almost 20% of language disorders, and SEM reveals that environmental factors play a greater role for normal twins than for language-impaired twins. Collapsing across language impaired and normal PEGI twins, shared or non-shared environmental factors account for 60% of twins' lexical abilities, 41% of the twins' syntactic abilities, and 32% of twins' phonological abilities.

Conflation of Perinatal and Postnatal Environmental Factors. Although twin studies *can* be used to tease apart the role of shared and nonshared environmental factors, classic twin studies *conflate* the role of perinatal and postnatal environment. (In this paper, the term *perinatal* refers to the period from 0 to 44 weeks gestation.) Examples of shared perinatal environmental factors include such things as gestational age at birth (GA), drugs that the twins were exposed to *in utero* and intrauterine infection, and examples of shared postnatal environmental factors include the quantity and quality of twins' linguistic input and the socioeconomic status (SES) of the family. Examples of nonshared perinatal environmental factors include cases in which twins are discrepant in birth weight (BW), perinatal brain injury, or perinatal drugs received, and examples of nonshared postnatal environmental factors include cases in which only one twin experiences a postnatal illness or injury.

The fact that twin studies conflate perinatal and postnatal environmental factors is critical for theories of language acquisition. Researchers who study language acquisition often implicitly assume that when one refers to the role of environmental factors on language, one is primarily referring to postnatal psychosocial factors. If such factors have a large impact on language development, this would support theories that argue that language development is largely the result of children's social and language environments (empiricist/emergentist theories). If, on the other hand, the environmental factors that affect children's language are predominantly perinatal (and, hence, unlikely to be psychosocial) or clearly biological (e.g., pre- or postnatal accidents, illnesses or toxins that affect the brain), this would support theories that argue that language acquisition is largely the result of children's innate, biological endowment (innatist/biological theories).

2. The Impact of Prenatal and Postnatal Environment on Language

Language Development in Twins. Twins' language development is typically slower than singletons' (e.g., Conway, Lytton, & Pysh, 1980; Dale, Dionne, Eley, & Plomin, 2000). Even when language-impaired twins are excluded and twins' ages are corrected for prematurity, twins' language lags about 2 months behind that of singletons' (Hay & O'Brien, 1983).

Twins' Prenatal Environmental Hardships. In the United States, over half of all twins are born prematurely (before 37 weeks gestation), whereas only about 10% of singletons are born prematurely (Guyer et al., 1999). In addition, twins are more likely to be born very prematurely (before 32 weeks gestation) than singletons (Holmgren & Hogberg, 2001). Premature children reach speech and language milestones later, perform more poorly on a wide range of speech and language tests, and are more likely to be diagnosed with speech and language disorders than their full-term peers (see, for example, Briscoe, Gathercole, & Marlow, 1998; Jennische & Sedin, 1999; Luoma, Herrgard, Martikainen, & Ahonen, 1998; Stevenson et al., 1988; Taylor, Klein, & Hack, 2000; Taylor, Klein, Minich, & Hack, 2000, and references therein). The more premature the child, the worse his linguistic skills, but that even children born between 32 and 36 weeks gestation do more poorly than children born full term (Hediger, Overpeck, Ruan, & Troendle, 2002; Huddy, Johnson, & Hope, 2001). Even preterm children with normal cognitive function and no major neurodevelopmental disabilities are 2 to 3 times more likely to suffer from written and spoken language disorders than full-term children, which suggests that language may be particularly vulnerable to the effects of prematurity.

In the US, twins are 10 times more likely to be born at low birth weights (less than 2500 grams) than singletons (Guyer et al., 1999). Low birth weight is a risk factor for language delays independent of prematurity (Low et al., 1992; Walther, 1988). Indeed, even at birth weights above 3000 grams, there is a significant positive relationship between birth weight and performance on a variety of linguistic tasks (Breslau, Chilcoat, DelDotto, & Andreski, 1996; Breslau et al., 2000). Even low birth weight full term children who are apparently neurologically intact do worse on language tasks than normal birth weight children (Breslau et al., 1996; Breslau et al., 2000; Low et al., 1992; Walther, 1988), suggesting that language may be particularly vulnerable to factors associated with low birth weight.

In addition to being more likely than singletons to be premature and low birth weight, twins are more likely to suffer from a host of prenatal complications (e.g., placental abruption, placental insufficiency, premature rupture of membranes, intrauterine infection, intrauterine hypoxia), intrapartum complications (e.g., nonvertex presentation, prolonged labor, intrapartum hemorrhage, umbilical cord prolapse, intrapartum hypoxia) and neonatal complications (e.g., severe jaundice, sepsis, respiratory distress, postnatal hypoxia). (For a review, see Stromswold, to appear.).

The perinatal environmental hardships described above are associated with hypoxic/ischemic brain injuries (Volpe, 2001). Because perisylvian language areas are in a vascular watershed, they are particularly vulnerable to hypoxic/ischemic injury. Oligodendroglia that are in the process of myelinization are more vulnerable to hypoxic injury (Perlman, 1998; Volpe, 2001), and the late myelinization of the temporal poles (Inder & Huppi, 2000) means that some of the brain regions that subserve language are in a vulnerable state for an extended period. Because their brain vasculature is less mature, the incidence of perinatal hypoxic/ischemic brain injuries is much higher for premature neonates than full-term neonates (Perlman, 1998). MRIs of preterm infants' brains have shown that even low-grade intraventricular hemorrhages or IVHs (which are traditionally said to have no clinical significance) are associated with marked reductions in cortical volumes (Vasileiadis et al., 2004). Furthermore, even if their neonatal ultrasounds were perfectly normal (i.e., no evidence of even low-grade IVHs), preterm children who suffered from even mild intrapartum hypoxia have worse cognitive and linguistic outcomes than preterm children who were not hypoxic (Hopkins-Golightly, Raz, & Sander, 2003). MRIs reveal that preterm children have smaller sensorimotor and midtemporal cortical volumes (i.e., cortical regions that include language areas), and the size of these areas is positively correlated with full scale, performance, and verbal IQs in preterm children (Peterson et al., 2000). A recent study confirms that the cortical areas that subserve written and spoken language are smaller in preterm children than full-term children (Reiss et al., 2004). Premature children's brains also process language differently than full term children' brains. For example, an fRMI study has shown that preterm children processed spoken words in the same way that full-term children processed meaningless strings of phonemes, with the fMRI signal correlating with verbal IQ scores in preterm but not full-term children (Peterson et al., 2002).

Twins' Postnatal Environmental Hardships. Although twins are at greatly increased risk for most perinatal complications, the linguistic delay of twins relative to singletons is usually taken to reflect the fact that twins experience postnatal hardships that singletons do not. Because twins have a sibling of the same age, the quantity and quality of twins' social interactions with parents is less that of singletons (Lytton, Conway, & Suave, 1977). To the extent that social interaction affects linguistic and cognitive development, twins should lag behind singletons in these domains. Postnatally, twins receive less and less complex adult linguistic input than singletons (see, Conway et al., 1980; Stafford, 1987; Thorpe, Rutter, & Greenwood, 2003 and references therein; Tomasello, Mannle, & Kruger, 1986). To the extent that adult linguistic input specifically affects children's language development, twins should lag behind singletons linguistically, but not cognitively.

Conway et al. (1980) has argued that differences in the complexity and frequency of maternal speech account for almost twice as much of the variance in children's language development as differences in Apgar scores, GA or BW. There are several reasons for questioning this conclusion. First, the study had only 12 twin pairs. Second, the twins had very benign perinatal histories, so adverse perinatal environment is less likely to affect language development. Third, there was less variance for neonatal variables than maternal variables, which probably reduced the predictive power of neonatal variables. Lastly, because twin and singleton data were collapsed in regression analyses, these data cannot be used to evaluate the relative importance of neonatal versus maternal variables in explaining twins' linguistic delays.

Two recent papers have explored the extent to which perinatal and postnatal factors account for the linguistic lag of twins relative to singletons (Rutter, Thorpe, Northstone, & Golding, 2003; Thorpe et al., 2003). Thorpe et al. (2003) have argued that maternal communicative variables account for much of the twin-singleton lag in neurologically intact twins born at 33 weeks or above. Although generally sound, there are several worrisome features of the study. First, because they looked at many potential maternal/familial factors, selected the 6 factors that were most predictive of language development, and summed these factors to create a composite factor, the importance of maternal communicative behaviors is likely inflated. Furthermore, because the intent of the study was to determine which factors accounted for the twin language lag, they eliminated from consideration factors that occurred at equal rates for twins and singletons. The companion paper (Rutter et al., 2003) argues that prenatal and obstetric complications play no role in the twin-singleton language lag. In light of the many studies that have shown that perinatal factors have a profound effect on language development, how can this be?

A careful reading of Rutter et al.'s (2003) paper reveals that the study suffers from several problems that may explain why perinatal factors did not affect language development in this study. For example, by eliminating any twins who were born before 33 weeks gestation, had clinical signs of neurological damage, or had evidence of brain damage on neural ultrasounds or MRIs, Rutter et al. (2003) removed those twins for whom perinatal factors were most likely to play a large role. Second, little information is provided about the perinatal characteristics of the twins. Thus, it is possible that lack of variability for these factors precluded them from having a statistically significant effect on language. Third, BWs and GAs of twins' and singletons' data were normalized separately (i.e., twins' values were normalized using only twin data, singletons' values were normalized using only singleton data) and the twins were born an average of 4 weeks earlier and 500 grams lighter than singletons. In essence, this normalization scheme assumes the conclusion that GA and BW do not account for the twin language lag. Fourth, the authors used 3 composite indices of perinatal risk, each of which includes many perinatal factors that have been shown to have no impact on neurodevelopment (e.g., 1 minute Apgar score, perineal lacerations) and excludes many perinatal factors that have been shown to affect neurodevelopment (e.g., infection, hypoxia, BW, hyperbilirubinemia). The composite measures also include measures that are subjective and could vary greatly in clinical severity (e.g., "complications during labour"). In short, the adequacy of the perinatal risk composite measures contrasts sharply with the adequacy of the psychosocial risk composite measures**.**

Using Genetic Twin Studies to Tease Apart the Role of Prenatal and Postnatal environment. Notice that the Conway et al., Rutter et al., and Thorpe et al. studies are *not* genetic twin studies. One can use genetic studies of twins to investigate the relative impact of perinatal and postnatal environmental factors, even though classic twin studies conflate the role of perinatal/biological and postnatal/sociolinguistic environment. One way of doing this is to use a measure of perinatal environment (e.g., GA) as a proxy for biological environmental and a measure of postnatal environment (e.g., SES) as a proxy for psychosocial environment. If MZ and DZ twin pairs have equally similar environments and a shared environmental factor affects linguistic development, it should increase the linguistic similarity of MZ and DZ twins equally. Thus, to the extent that a shared environmental factor affects linguistic development, estimates of the impact of genetic factors on linguistic abilities (A and D) will be lowered and estimates of the impact of shared environment (C) will be raised. So, for example, if twins' linguistic delays are the result of adverse perinatal environment, we would expect low GA twins (i.e., twins at high biological risk) to have higher shared environment estimates (C) and lower genetic estimates (A and D) than high GA twins (i.e., twins at low biological risk). If twins' linguistic delays are due to adverse postnatal environment, low SES twins (i.e., twins at high psychosocial risk) should have higher C's and lower A's and D's than high SES twins (i.e., twins at low psychosocial risk). The greater the impact of an environmental factor on language development, the greater the discrepancy in environmental and genetic estimates for language for twins who are at high versus low risk for that environmental factor.

Koeppen-Schomerus et al. (2000) conducted analyses of data from the Twins Early Development Study (TEDS) that address the question of how prematurity affects heritability estimates for verbal and nonverbal development. In this intriguing study, genetic factors played a significant role in the verbal and nonverbal development of moderately preterm and full-term twins, accounting for between 18-32% of the variance. However, for twins born very prematurely (< 32 weeks gestation), the effect of shared environmental factors completely overshadowed the effect of genetics. A study by Turkheimer et al. (2003) suggests that impoverished postnatal environment <u>does</u> diminish the impact that of heritability factors on IQ. In this study, for twins living at or near the poverty level, 58% of the variance in full scale IQ was accounted for by shared environment (C) and 10% of the variance was explained by heritable factors (A). For twins with affluent families, the proportions were almost exactly reversed (A = .72, C = .15). However, because different twins were studied in the two studies, one cannot determine the relative importance of perinatal (biological) and postnatal (psychosocial) environment. The following study investigates, in the same group of twins, how prenatal and postnatal environment affects linguistic and nonlinguistic development.

3. The Developmental Impact of Perinatal and Postnatal Environment

Participants. The results reported in this paper are for the first 267 same-sex twin pairs who were between the ages of 2 and 6 when they enrolled in our on-going longitudinal PEGI study. Of the twin pairs, 145 were MZ and 122 were DZ. Fifty-one percent of the twins were male, and 49% were female. **(**Zygosity of twins was determined using a questionnaire (Goldsmith, 1991) that asks about the physical and developmental similarity of young twins, and has a reliability of over 95%.) The mean BW of the MZ twins was 2294 grams (SD = 583 grams) and the mean BW of the DZ twins was 2309 grams (SD = 620 grams). The mean GA of the MZ twins was 35.1 weeks (SD = 2.76 weeks) and the mean GA of the DZ twins was 35.0 weeks (SD = 3.16).

Developmental Measures. Twins' development was assessed using the parent-administered Ages and Stages (AS) communication (language), problem solving (cognitive), gross motor, fine motor, and social-personal (social) tests (Bricker & Squires, 1999). The AS tests were normed on 10,000 at-risk and normal children, and results have been shown to be valid and reliable.

Prenatal and Postnatal Risk Measures. Parents completed the PEGI Twin Perinatal Risk Factor Questionnaire (Stromswold, 2003). This questionnaire asks about family history and demographics, pre-pregnancy health of mother, pregnancy, intrapartum, neonatal and postnatal complications, therapies and treatments, neuropsychological diagnoses and when developmental milestones were achieved. Twins were divided into two prenatal risk groups based on GA, with the high perinatal risk twins being born at GAs of 32 weeks or less and the low perinatal risk twins being born at GAs of 33 weeks or more. Twins were also divided into two postnatal risk groups based on SES. SES was calculated by summing the mother's education score (on a 4 point scale), the father's education score (on a 4 point scale) and the family income score (on a 5 point scale). High postnatal risk twins had an SES score of 9 or less and low postnatal risk twins had an SES of 10 or greater.

3. Results

Perinatal Environment Results. When twins were divided into low GA (≤ 32 weeks GA, Figure 1a) and high GA (≥ 33 weeks GA, Figure 1b) groups, additive genetic factors (A) accounted for 60% of the variance in high GA twins'

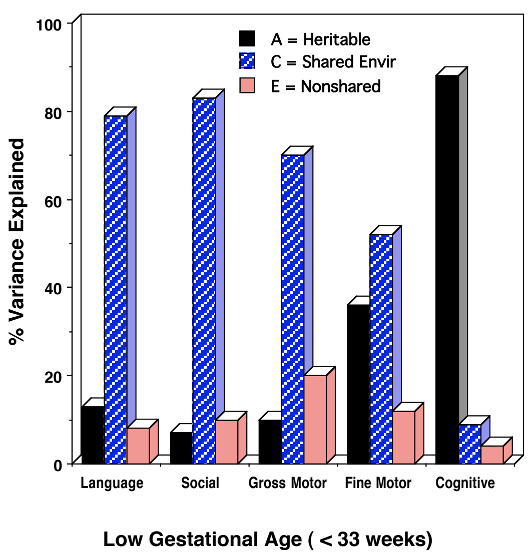

Figure 1a

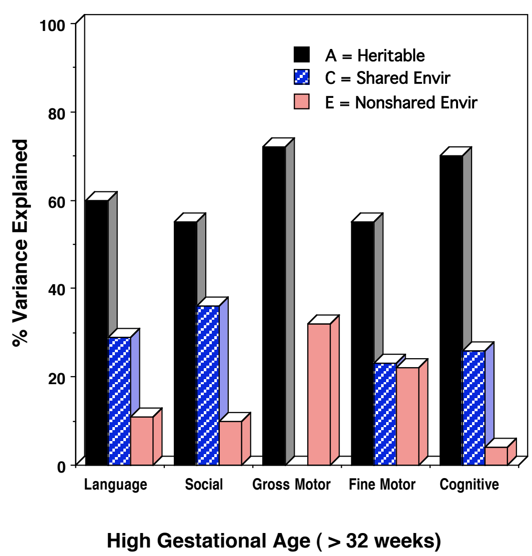

Figure 1b

Figure 1: Gestational Age at Birth and Estimates of the Role of Heritable and Environmental Factors on Linguistic and Non- Linguistic Development

language scores and only 13% of the variance in low GA twins' language scores. Shared environmental factors (C) accounted for 79% of the variance in low GA twins' language scores and only 29% of the variance in high GA twins' language scores. Results were similar for gross motor, fine motor, and social scores, but not cognitive scores where heritable factors affected both GA groups similarly (low GA twins A = .88, C = .09; high GA twins A = .70 C = .26). In other words, perinatal hardship decreased estimates of the role of genetic factors for language but *not* cognition, and perinatal hardship inflated estimates of the role of shared environmental factors for language but *not* cognition.

Postnatal Environment Results. When twins are divided into low SES (SES score ≤ 9, Figure 2a) and high SES (SES ≥ 10, Figure 2b) groups, heritability and shared environment estimates of language scores were virtually identical for the two SES groups (low SES A= .39, C = .52; high SES A = .38, C = .52). For cognitive scores, shared environmental factors accounted for about 8 times more variance than genetic factors for the low SES twins (A = .10, C = .77), whereas shared environmental factors accounted for only 1.5 times more variance than genetic factors for the high SES twins, (A = .32, C = .49). In other

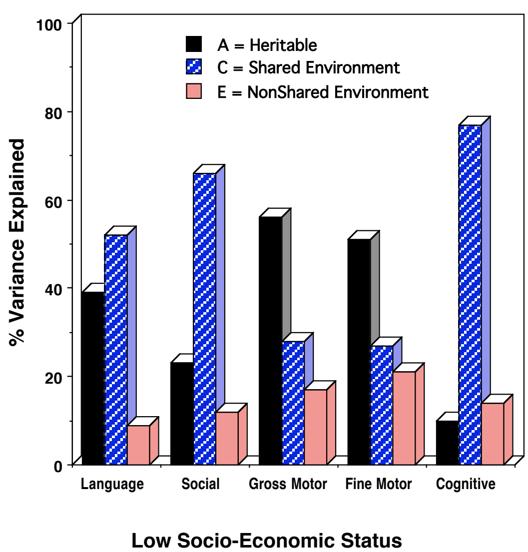

Figure 2a

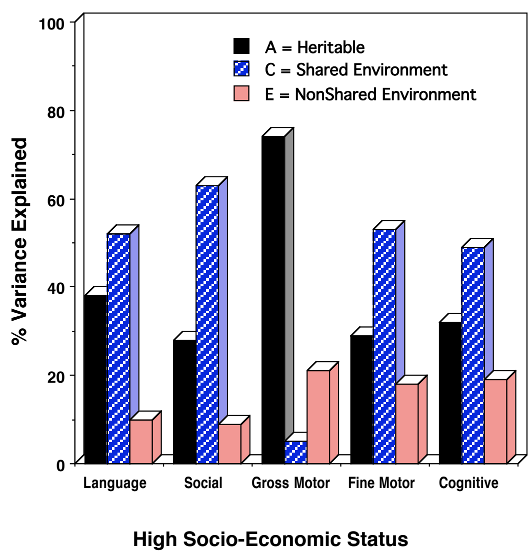

Figure 2b

Figure 2: Socio-Economic Status and Estimates of the Role of Heritable and Environmental Factors on Linguistic and Non- Linguistic Development

words, the impact of *postnatal* hardship on linguistic and cognitive development was the opposite of the impact of *perinatal* hardship. Perinatal hardship decreased estimates of the role of genetic factors for language but not cognition, and postnatal hardship decreased estimates of the role of genetic factors for cognition but not language. Perinatal hardship inflated the role of shared environment for language but not cognition, and postnatal hardship inflated estimates of the role of shared environmental factors for cognition but not language. Simply put, perinatal environment affected linguistic development and postnatal environment affected cognitive development.

4. Discussion and Implications

The results of this study suggest that twin studies that include high perinatal risk twins (e.g., twins who are premature or low BW or who suffered from other perinatal complications associated with hypoxia) will underestimate the role of genetic factors in language development and overestimate the role of shared environmental factors in language development. Indeed, given the relationship between GA and language development, even studies that exclude premature twins probably underestimate the role of genetic factors in language development because even full-term twins, on average, are born 3 to 4 weeks before full term singletons. Similarly, given the relationship between BW and language development, even twin studies that only include normal BW twins are likely to underestimate the role of genetic factors because even normal BW twins weigh, on average, about 500 grams less than normal BW singletons.

Perinatal shared environment mainly reflects biological factors many of which affect neural development, whereas postnatal shared environment mainly reflects psychosocial factors (e.g., adult-child social interactions and adult linguistic input). Thus, our finding that perinatal environment but not postnatal environment affects linguistic development is consistent with nativist/biological theories of language acquisition (that argue that language acquisition is largely the result of children's innate, biological endowment) and calls into question empiricist/emergentist theories (that argue that language development is largely the result of children's social and language environment). In short, when it comes to language development, children's neural status is more important than the adult linguistic input they receive. For cognitive development, the results are essentially the opposite: when it comes to cognitive development, children's postnatal psychosocial environment is more important than their neural status.

Gross motor development is generally believed to be largely the result of innate, biological factors with postnatal environmental factors playing a relatively minor role. Thus, the finding that gross motor development (and to a lesser extent fine motor development) patterns with language development (i.e., prenatal environment affects both gross motor and language development whereas postnatal environment affects neither) provides further support for nativist/biological theories of language acquisition. It is somewhat puzzling, however, that social development patterns with linguistic development. It could be that, like language development, children's social development is largely due to their biological endowment. However, this finding may merely reflect that some of the social AS test items have an obvious linguistic component (e.g., "does your child tell you the names of two or more playmates, not including brothers and sisters?"). The only way to tease these two possibilities apart is to conduct further studies using "cleaner" measures of social development.

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