Research Article

NATURE, NURTURE, AND COGNITIVE DEVELOPMENT FROM 1 TO 16 YEARS: A Parent-Offspring Adoption Study

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Abstract—*Children increasingly resemble their parents in cognitive abilities from infancy through adolescence Results obtained from a 20-year longitudinal adoption study of 245 adopted children and their biological and adoptive parents, as well as 245 matched nonadoptive (control) parents and offspring, show that this increasing resemblance is due to genetic factors Adopted children resemble their adoptive parents slightly in early childhood but not at all in middle childhood or adolescence In contrast, during childhood and adolescence, adopted children become more like their biological parents, and to the same degree as children and parents in control families Although these results were strongest for general cognitive ability and verbal ability similar results were found for other specific cognitive abilities—spatial ability, speed of processing, and recognition memory These findings indicate that within this population, genes that stably affect cognitive abilities in adulthood do not all come into play until adolescence and that environmental factors that contribute to cognitive development are not correlated with parents' cognitive ability*

Although family, twin, and adoption studies converge on the conclusion that general cognitive ability is one of the most highly heritable behavioral traits (Plomin, DeFries, McClearn, & Rutter, 1997), much remains to be learned about the nature and nurture of cognitive abilities (Plomin & Petrill, 1997) One issue is to chart the developmental course of genetic and environmental influences In this regard, two surprising hypotheses are emerging from studies across the life span Although it would be reasonable to expect that differences in experience gain in importance as time goes by, research to date suggests the opposite Comparisons across studies indicate, first, that the heritability of general cognitive ability may increase from childhood to adolescence to adulthood and, second, that the effects of shared family environment may decrease to negligible levels by adolescence (McCartney, Harris, & Bernieri, 1990, McGue, Bouchard, Iacono, & Lykken, 1993, Plomin, 1986)

Another issue is to move beyond general cognitive ability, for which many twin and adoption studies point to significant genetic influence (Bouchard & McGue, 1981), to investigate specific cognitive abilities, about which much less is known (Plomin et al , 1997) General cognitive ability represents what diverse cognitive abilities have in common It can be assessed as an unrotated principal component derived from factor analysis of diverse tests of cognitive abilities, although it is frequently indexed by a total score on intelligence (IQ) tests (Brody, 1992) There is of course more to cognitive abilities than general cognitive ability In the widely accepted hierarchical model of cognitive abilities, specific cognitive abilities include broad factors such as spatial, verbal, speed-of-processing, and memory abilities, each indexed by what is in common among several tests of the ability (Carroll, 1993)

In 1975, we launched a prospective, longitudinal adoption study of cognitive development, the Colorado Adoption Project (CAP), that could test developmental hypotheses about change and continuity in relation to general and specific cognitive abilities The adoption design is powerful because it capitalizes on the intervention of adoption to disentangle genetic and environmental sources of resemblance between parents and offspring by comparing biological parents and their adopted-away offspring, who share genes but not environment, with adoptive parents and their adopted children, who share environment but not genes Here we report, for the first time, longitudinal results from 1 to 16 years of age for the CAP, which is the largest and longest adoption study of its kind The sample consists of 245 biological mothers who relinquished their children for adoption at birth, the adoptive parents who adopted these children, the adopted children themselves, and 245 control (nonadoptive) parents and their children The control families were matched to the adoptive families (DeFries Plomin & Fulker, 1994)

METHODS

Sample

The biological and adoptive parents were recruited through two adoption agencies in Denver, Colorado, between 1975 and 1982 Most of the biological mothers were recruited and tested prior to the birth of the child A fifth of the biological fathers were tested, previous adoption studies of cognitive ability have not reported any test data on biological fathers Children were placed in their adoptive homes at the average age of 29 days Adoptive parents were recruited when the adopted child was 7 months old on average A matched sample of control families was recruited from the same area, we used hospital birth records and telephone interviews to match them to the adoptive families on five criteria the gender of the proband, the number of children in the family, the age of the father (±5 years), the occupational status of the father (±8 points on the National Opinion Research Center occupational rating scale), and the father's years of education (±2 years) Informed consent was obtained, and the rights of subjects were protected

Most of the biological parents (90%) and adoptive parents (95%) were European American (based on self-reported ethnicity), the remaining parents were either Hispanic or Asian American The variability in socioeconomic status (SES) was representative of the U S population, but the families were above the national average in mean SES Although the adoptive and control fathers had somewhat higher

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SES than the biological fathers, the fathers of all three groups of fathers (i e , the adopted children's biological and adoptive grandfathers and the control children's grandfathers) had similar means and variances for SES (Plomin & DeFries, 1985), suggesting that the biological parents of the adopted children were not from disadvantaged backgrounds The biological parents were younger on average ([illegible] years) than the adoptive parents (33 years), which could partly explain their lower SES

Measures and Procedures

The biological mothers were usually tested in their third trimester of pregnancy, and the adoptive and control parents were usually tested during the child's 1st year The parents were administered a 3-hr battery of measures that included 13 tests of specific cognitive abilities The tests, their reliability, their factor structure, and the methods applied for gender and age adjustment are described elsewhere (DeFries, Plomin, Vandenberg, & Kuse, 1981) General cognitive ability was indexed by an unrotated principal component Specific cognitive abilities—verbal, spatial, speed-of-processing, and memory abilities—were represented by factor scores following orthogonal rotation, rather than using a hierarchical factor analytic procedure In addition, when the children were 7 years old, adoptive and control parents were tested on a standard IQ test the Wechsler Adult Intelligence Scale (WAIS, Wechsler, 1972) Because the adoption agencies precondition for testing the biological parents was that we would not contact them again, the WAIS was not administered to the biological parents The average WAIS IQ scores (and standard deviations) were 112 5 (12 0) for adoptive fathers, 107 6 (11 1) for adoptive mothers 114 9 (11 6) for control fathers, and 110 4 (10 9) for control mothers

The children (263 boys and 226 girls at 1 year of age when the sample was largest, 1 of the 490 was not tested at 1 year) were tested in their homes at 1, 2, 3, and 4 years of age and in the laboratory at 7, 12 and 16 years using standard intelligence tests from which IQ scores were derived the Bayley Scales of Infant Development (Bayley, 1969) at ages 1 and 2, the Stanford-Binet Intelligence Scale-Form L-M (Terman & Merrill, 1973) at ages 3 and 4 the Wechsler Intelligence Scale for Children-Revised (Wechsler, 1974) at ages 7 and 12 and the WAIS at age 16 The children were tested on a separate battery of tests of specific cognitive abilities in their homes at 3 and 4 years of age (Rice, Corley, Fulker, & Plomin, 1986) and in the laboratory at 7, 12, and 16 years (DeFries et al , 1994) In addition, the children were tested on a battery of tests of specific cognitive abilities administered by telephone at 9, 10, and 14 years (Cardon, Corley, DeFries, & Plomin, 1992) From these tests of specific cognitive abilities, we extracted an unrotated principal component to represent general cognitive ability Results of rotated factor analyses were used to create specific indices of verbal, spatial speed-of-processing, and memory abilities by averaging z scores of the two or three tests that loaded most highly on each factor (DeFries et al , 1981) At 16 years, the children were administered the same test battery that their parents completed at the beginning of the project, as well as the WAIS The average WAIS IQ scores were 104 8 (SD = 11 1) for adopted children and 108 5 (SD = 10 1) for control children

RESULTS

Figure 1 presents parent-offspring correlations for the three types of relationships for general cognitive ability as assessed by unrotated principal component scores extracted from tests of specific cognitive abilities for the parents and for the children at 3, 4, 7, 9, 10 12, 14, and 16 years The average correlation between adoptive parents and their adopted children is 09 at 3 years, 00 at 4 years, 01 in middle childhood (7, 9 and 10 years), − 06 in early adolescence (12 and 14 years), and 03 in late adolescence (16 years) These results suggest that environmental factors correlated with parents' general cognitive ability have little effect on children's cognitive ability

Correlations between biological parents (weighted averages for mothers and fathers) and their adopted-away offspring also start off at modest levels at 3 and 4 years (12) However, unlike adoptive-parent/adopted-child correlations correlations between biological parents and their adopted-away offspring increase during middle childhood (18), early adolescence (20), and late adolescence (38) The increasing resemblance between adopted children and their biological parents, with correlations rising from about 1 in early childhood to about 2 in middle childhood to about 3 in adolescence, suggests increasing genetic influence Results for control parents are similar to those for biological parents Correlations of 19 in early childhood, 24 in middle childhood, 28 in early adolescence, and 31 in late adolescence indicate again that parent-offspring resemblance for general cognitive ability is largely due to genetic influences It should be noted that parents and offspring share mainly additive genetic effects that occur when the independent effects of genes add up to affect the phenotype, they do not share dominance and higher order, interactive effects of genes (Plomin et al , 1997) For this reason, parent-offspring designs are said to estimate narrow heritability In contrast, broad heritability includes both additive and nonadditive effects and can be estimated by the twin design because identical twins share nonaddi-

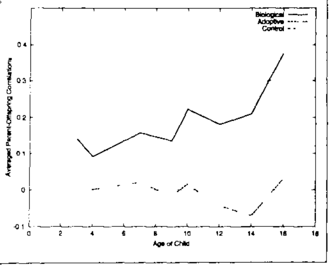

Fig 1 Parent-offspring correlations between parents' first principal component scores and children's first principal component scores derived from tests of specific cognitive abilities for adoptive, biological, and control parents and their children at 3, 4, 7, 9, 10, 12, 14, and 16 years Parent-offspring correlations are weighted averages for mothers and fathers to simplify the presentation (The correlations for mothers and fathers were similar) Full correlation matrices are available from the first author The Ns range from 33 to 44 for biological fathers, 159 to 195 for biological mothers, 153 to 194 for adoptive parents, and 136 to 216 for control parents

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tive as well as additive effects of genes. However, in the case of cognitive abilities, there is little evidence for nonadditive genetic influence. For example, parent-offspring adoption studies and twin studies yield similar results.

We also examined correlations between parents' IQ, assessed for adoptive and control parents when the children were 7 years old, and children's IQ, assessed at 1, 2, 3, 4, 7, 12, and 16 years. The results, shown in Figure 2, suggest some resemblance between adoptive parents and their adopted children in infancy (.13 at ages 1 and 2) and early childhood (.20 at ages 3 and 4), followed by a decline in middle childhood (.07 at age 7) and adolescence (.00 at ages 12 and 16). Children in control families, however, steadily become more similar to their parents: .09 in infancy, .17 in early childhood, .19 in middle childhood, and .30 in adolescence. This pattern of results for IQ scores replicates the results for general cognitive ability as indexed by first principal component scores (Fig. 1), again indicating increasing heritability. This finding confirms and extends our previous report of a *trend in the direction of increasing heritability from 1 to 7 years of age* (Fulker, DeFries, & Plomin, 1988) and also supports similar trends seen in Skodak and Skeels's (1949) longitudinal adoption study and in Wilson's (1983) longitudinal twin study.

Figure 3 summarizes the results for factor scores for the specific cognitive abilities: verbal ability, spatial ability, speed of processing, and recognition memory. The developmental patterns of parent-child resemblance are similar to the pattern seen for general cognitive ability. Resemblance increases between biological parents and their adopted-away offspring, a pattern of results similar to that for control parents and offspring. These correlations reach their highest levels for verbal ability. For adoptive parents and their adopted children, early resemblance for verbal ability disappears by middle childhood. For spatial ability, speed of processing, and memory, correlations between adoptive parents and their adopted children are low at all ages.

The data at 16 years of age are particularly interesting because the children were administered the same battery of cognitive tests that

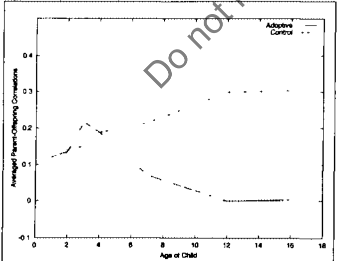

Fig. 2. Parent-offspring correlations between parents' IQ scores and children's IQ scores for adoptive and control parents and their children at 1, 2, 3, 4, 7, 12, and 16 years. Parent-offspring correlations are weighted averages for mothers and fathers. The *N*s range from 136 to 202 for adoptive parents and 127 to 224 for control parents.

their parents completed 16 years earlier. The parent-offspring co[rre]lations for general and specific cognitive abilities are shown in T[ab]le 1. For general cognitive ability assessed by principal compon[en]t scores, correlations between adoptive parents and their children [ar]e near zero. For genetically related parents and offspring, correlati[on]s are about .30 for both biological parents and control parents. Cor[re]lations for specific cognitive abilities also show negligible correla[-]tions between adoptive parents and their children, whereas correlations between genetically related parents and offspring are moderate, .35 on average for verbal ability and about .20 on average for the other three specific cognitive abilities.

Correlations between adoptive parents and their adopted children provide a direct estimate of variance of cognitive abilities accounted for by environmental transmission from parent to child. The near-zero correlations indicate that this environmental component of variance is negligible. In contrast, correlations between biological parents and their adopted-away offspring directly estimate half of the genetic contribution to the variance because the degree of genetic relatedness between parent and offspring is 50%. Doubling these correlations suggests heritabilities of about .60 for general cognitive ability and .70 for verbal ability, with somewhat lower heritabilities for the other specific cognitive abilities. However, these heritability estimates are inflated by assortative mating (resemblance between spouses), which typically results in spousal correlations of about .30. Selective placement (resemblance between biological and adoptive parents) could also inflate these estimates because it can increase resemblance between biological parents and their children, although selective placement for cognitive abilities is inconsequential in CAP, as we discuss shortly.

Model fitting can take assortative mating and selective placement into account while estimating genetic and environmental sources of transmission from parent to child as well as the correlation between genetic and environmental sources (genotype-environment correlation). In addition, model fitting can be used to compare alternative models, especially more parsimonious models in which parameters are equated or dropped. Using a path model described elsewhere (Fulker et al., 1988), we applied maximum-likelihood model-fitting analysis to the CAP data for 16-year-old adopted and control children and their parents.

Initially, a full model was fitted to data for each cognitive ability which involved 20 degrees of freedom (31 observations minus 11 estimated parameters). A series of reduced models was then fitted to assess the significance of the omitted parameters, with similar results obtained for general and specific cognitive abilities. First, the four selective placement parameters were dropped. A nonsignificant reduction of fit from the full to the reduced model resulted (for general cognitive ability, $\Delta\chi^2[4] = 1.85$, $p > .75$), indicating that selective placement was not significant. Assortative mating parameters for the three types of parents (estimated as .21 for the adoptive and control parents and .17 for the biological parents for general cognitive ability) were equated with no significant loss of fit, $\Delta\chi^2(1) = 0.09$, $p > .75$. Maternal and paternal environmental transmission parameters were also equated with no significant loss of fit, $\Delta\chi^2(1) = 2.86$, $p > .05$.

With the number of parameters reduced from 11 to 5 for this reduced model, the chi-square goodness-of-fit statistic has 26 degrees of freedom. The fits of this parsimonious model for general cognitiv[e] ability and the four specific cognitive abilities are adequate, as show[n] in Table 2. Parameter estimates resulting from the fit of this reduce[d]

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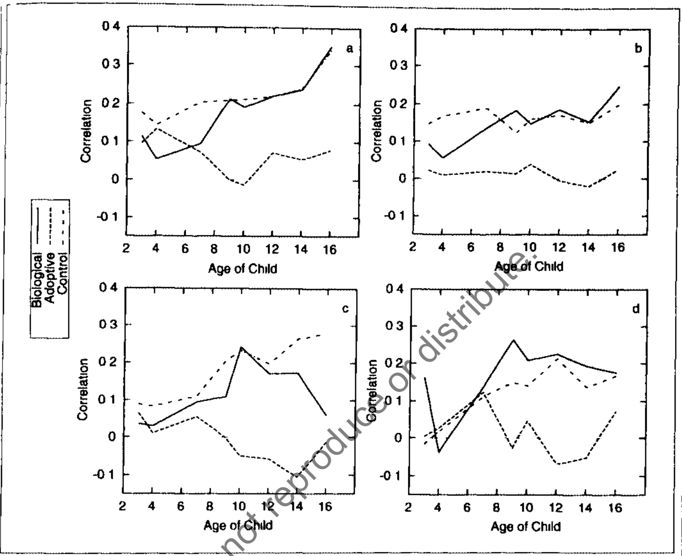

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Fig. 3. Parent-offspring correlations for factor scores for specific cognitive abilities for adoptive, biological, and control parents and their children at 3, 4, 7, 9, 10, 12, 14, and 16 years. Correlations are shown for verbal ability (a), spatial ability (b), speed of processing (c), and recognition memory (d). Parent-offspring correlations are weighted averages for mothers and fathers. The *N*s range from 33 to 44 for biological fathers, 159 to 180 for biological mothers, 153 to 197 for adoptive parents, and 136 to 217 for control parents.

model to the data correspond to the conclusions gleaned from the simple correlations in Table 1. For general cognitive ability, heritability is substantial, about .56, with assortative mating taken into account and selective placement set to zero. This estimate is similar to estimates that emerge from meta-analyses of general cognitive ability from previous adoption and twin studies with subjects widely varying in age (Chipuer, Rovine, & Plomin, 1990; Loehlin, 1989). Environmental transmission from parent to child is negligible. The inconsequential estimate of genotype-environment correlation is to be expected given the negligible influence of environmental transmission from parent to child. The assortative mating estimate is similar to the actual correlation between mothers and fathers (see footnote to Table 2).

For specific cognitive abilities, heritability for verbal ability (.54) is similar to the heritability of general cognitive ability (.56). Heritability is somewhat lower for spatial ability (.39), speed of processing (.26), and recognition memory (.26). Environmental transmission from parent to child is negligible for all four specific cognitive abilities, as are genotype-environment correlations. Assortative mating is also highest for verbal ability (.25) and lower for spatial ability (.06), speed of processing (.13), and memory (.12).

DISCUSSION

These results suggesting an increasing role of nature and a decreasing role for nurture cannot be safely generalized beyond the CAP samples. Although the CAP adoptive and control families are representative of the U.S. population in SES variance, they are above average in mean SES. The CAP families also have mean WAIS scores above the mean of the WAIS standardization sample, and their WAIS variance is below the variance of the standardization sample, although

Table 1 *Parent-child correlations for adoptive, biological and control parents and their 16-year-old children for general and specific cognitive abilities*

Parent	Number of pairs	General cognitive ability[a]	Specific cognitive abilities			
			Verbal	Spatial	Speed	Memory
Adoptive father	153	11	14	01	− 01	07
Adoptive mother	157	− 05	02	03	− 02	08
Biological father	33	32	45**	12	− 29	− 07
Biological mother	159	39**	33**	27**	13	23**
Control father	137	33**	40**	24**	29**	20*
Control mother	136	28**	28**	16	27**	14

[a]Assessed by principal component scores
$^{*}p < 05$ $^{**}p < 01$

this pattern is typical of normal populations that do not include individuals institutionalized for mental retardation (Brody 1992) Thus, although we do not claim that the CAP samples are perfectly representative, they are reasonably representative of the middle 90% of the population Moreover, the CAP design is internally consistent in that the control families are matched to the adoptive families, and there was no selective placement of adopted children into their adoptive families on the basis of the IQ of their biological parents However, it is important to note that the CAP families do not include the environmental extremes of disadvantage, neglect, and abuse Genetic and environmental results could well differ at such extremes

In summary, results obtained from the CAP tell a simple story about the genetic nature of cognitive abilities Genetic influence increases monotonically from infancy to childhood to adolescence A minor subplot is that genetic influences appear strongest for general cognitive ability and for the specific cognitive ability of verbal ability, although genetic influence is nonetheless substantial and not significantly different for the other specific cognitive abilities

Because the CAP is a parent-offspring design with adult parents and young offspring, it reveals a unique class of genetic influence Rather than including all genetic influences on individual differences in cognitive abilities in childhood or in adulthood, as comparison of same-aged twins would do, the CAP assesses only genetic influences that affect cognitive abilities both in the offspring as children and in their adult parents From this perspective, the CAP results can be interpreted more precisely as showing that genetic effects on adult

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Table 2. *Model-fitting parameter estimates for CAP data for 16-year-olds resulting from the fit of a parsimonious model of genetic and environmental transmission for general and specific cognitive abilities*

Parameter	General cognitive ability[a]	Specific cognitive abilities			
		Verbal	Spatial	Speed	Memory
Heritability	56	54	39	26	26
Environmental transmission	01	02	01	06	05
Assortative mating	21	25	06	13	12
Genotype-environment correlation	01	02	01	04	03
$\chi^2(26)$	26 1	28 1	28 0	21 4	33 7
p	> 45	> 35	> 35	> 70	> 10

Note Estimates are based on a covariance model in which selective placement parameters were set to zero assortative mating was equated for the three types of parents, and maternal and paternal environmental transmission parameters were equated Selective placement correlations were set to zero because they were negligible Correlations between biological mothers and adoptive mothers were 00 for general cognitive ability (assessed by principal component scores) 06 for verbal ability 05 for spatial ability, − 08 for speed of processing and − 08 for recognition memory between biological mothers and adoptive fathers the correlations were − 02 10 − 05 − 05 and 01 Assortative mating correlations between mothers and fathers for general cognitive ability (assessed by principal component scores) were 23 for biological parents 24 for adoptive parents and 16 for control parents For specific cognitive abilities assortative mating correlations for the three types of parents respectively were 08 29, and 24 for verbal ability, 01, 10, and 04 for spatial ability 13, 11, and 15 for speed of processing, and − 01 09, and 22 for recognition memory Maternal and paternal environmental transmission parameters were equated because doing so led to no significant loss of fit in the model as shown in Table 1, for example, adoptive fathers and mothers generally yielded similar parent-offspring correlations
[a]Assessed by principal component scores

cognitive abilities are not manifested only in adulthood, but also to a considerable extent in adolescence, to a lesser extent in childhood, and even to some slight extent in infancy In terms of molecular genetic attempts to identify specific genes responsible for genetic variance in cognitive abilities (Plomin, 1997, Plomin et al, 1995), this finding implies that some genes could be found in infancy that predict adult cognitive ability, and the chances increase in childhood and even more in adolescence However, not all of the genes associated with adult cognitive ability come into play until adolescence It is also possible that the increasing genetic relatedness between parent and offspring reflects increasing validity of measurement of cognitive abilities from infancy through adolescence

The environmental story is also simple but even more surprising Environmental transmission from parent to offspring has little effect on later cognitive development This finding is especially surprising for verbal ability, which would seem a priori to be most conducive to environmental transmission from parent to child We hasten to add that this conclusion does not imply that parents have no effect on their children's cognitive development What it means is that environmental factors related to parents' cognitive abilities have no consistent long-term effects that make the cognitive development of one couple's children different from the cognitive development of children in other families Other aspects of parenting might affect cognitive development

This is a finding of great importance because the search for environmental correlates of cognitive development has focused on aspects of the family environment correlated with parents' cognitive ability These new data suggest that the search should be directed elsewhere, perhaps to attitudes about education and achievement or to more general emotional factors such as parental warmth and support However, other genetic research constrains this search for environmental correlates even more The research shows that environmental factors that affect cognitive development beyond adolescence are not shared by children growing up in the same family (Dunn & Plomin, 1990, Plomin, Chipuer, & Neiderhiser, 1994) That is, whatever they may be, the environmental influences salient to cognitive development operate to make children growing up in the same family different, not similar This discovery provides a key to unlock the mystery of environmental influences on cognitive development Researchers need to ask what makes two children growing up in the same family so different If parents affect their children's cognitive development at all, their environmental impact must involve aspects of parenting that make children in the same family different, not similar, in cognitive abilities More generally, these findings suggest that the search for environmental influences on cognitive development might profit from looking beyond the family environment to extrafamilial factors such as friends, peers, and teachers

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