

Family environment and the malleability of cognitive ability: A Swedish national home-reared and adopted-away cosibling control study

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Cognitive ability strongly aggregates in families, and prior twin and adoption studies have suggested that this is the result of both genetic and environmental factors. In this study, we used a powerful design—home-reared and adopted-away cosibling controls—to investigate the role of the rearing environment in cognitive ability. We identified, from a complete national Swedish sample of male–male siblings, 436 full-sibships in which at least one member was reared by one or more biological parents and the other by adoptive parents. IQ was measured at age 18–20 as part of the Swedish military service conscription examination. Parental educational level was rated on a 5-point scale. Controlling for clustering of offspring within biological families, the adopted siblings had an IQ 4.41 (SE = 0.75) points higher than their nonadopted siblings. Each additional unit of rearing parental education was associated with 1.71 (SE = 0.44) units of IQ. We replicated these results in 2,341 male–male half-sibships, in which, controlling for clustering within families, adoption was associated with a gain of IQ of 3.18 (SE = 0.34) points. Each additional unit of rearing parental education was associated with 1.94 (SE = 0.18) IQ units. Using full- and half-sibling sets matched for genetic background, we found replicated evidence that (i) rearing environment affects IQ measured in late adolescence, and (ii) a portion of the IQ of adopted siblings could be explained by the educational level of their adoptive parents.

cognitive ability | environment | adoption | rearing | cosibling control

Adopted children provide one of the strongest tests of the environmental malleability of cognitive ability (1–3). Adoption studies are informative about genetic and environmental aspects of development and individual and group differences in outcome (4). Correlations between the abilities of adopted children and measures of the ability of their biological and adoptive parents are a classical method for estimating genetic and environmental cross-generational contributions to cognitive development. Comparisons between the average ability of adopted children and their biological parents or nonadopted siblings estimate the extent to which cognitive ability can be modified by environmental changes.

The two complementary aspects of adoption studies—comparisons of mean IQ of adoptive offspring and their biological relatives on the one hand, and correlations among adopted offspring and their biological and adoptive parents on the other hand—have sometimes seemed to reflect different processes. In general, when adopted offspring have been compared with their biological parents or nonadopted offspring, it appears that their IQs have been enhanced by the adoption (5). The classic series of studies of this kind was reported by Skodak and Skeels (6). Skodak and Skeels reported on a longitudinal study of 139 children placed for adoption before the age of 6 mo. The children were administered cognitive ability tests at a mean of 2 y, with follow-ups at 4, 7, and 13 y, by which time attrition had reduced the sample to 100. The mean IQ of 63 tested mothers

from the final sample of 100 was 85.7, whereas the mean IQ of the adopted children was 116.8 at 2 y, slowly decreasing to ~108 by age 13.

There were, however, strong criticisms of Skodak and Skeels' methodology and conclusions. McNemar (7) demonstrated that the cognitive ability of the biological parents was almost certainly underestimated. Munsinger added the criticism that inadequate controls for attrition were applied, which seems to have favored the inclusion of the higher-ability children (8). Moreover, approximately a third of the effect appears to be attributable to the Flynn effect—i.e., increases in the mean level of cognitive ability between the maternal and offspring generations (9).

Nevertheless, more recent studies of adopted children support the conclusion that average IQ is increased by adoption into more prosperous homes. A series of studies from France reported on four groups of adopted children, selected on the basis of relatively low or relatively high socioeconomic status of their biological parents, and the low or high status of their adoptive parents (10). The resulting four groups approximated the “cross-fostering” design used in genetic studies of experimental animals, including a very unusual group of children whose adoptive parents were socioeconomically worse off than their biological parents. Results demonstrated significant IQ advantages both in the children born to more advantaged biological parents and those raised by more advantaged adoptive parents.

Families in which at least one sibling is home-reared by the biological parents and at least one other sibling is adopted away provide an especially powerful version of the adoption design, and they have also appeared to confirm Skodak and Skeels'

Significance

Individual differences in cognitive ability result from a complex admixture of genetic and environmental influences. Adopted children are one way to estimate the degree of malleability of cognitive ability in response to environmental change in the context of a scientific design that can control for genetic differences among individuals. Sibling pairs in which one member is adopted away and the other reared by biological parents are a particularly powerful research design. In a large population-based sample of separated siblings from Sweden, we demonstrate that adoption into improved socioeconomic circumstances is associated with a significant advantage in IQ at age 18. We replicate the finding in a parallel sample of half-siblings.

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Table 1. Descriptive statistics of the full- and half-sibling samples

Sibling sample	No. of individuals	Biological parent education, mean (SD)	Adoptive parent education, mean (SD)	IQ score, mean (SD)
Full-siblings				
Reared	590	2.01 (1.0)		92.0 (14.1)
Adopted-away	453	2.01 (1.0)	2.64 (1.3)	96.9 (14.5)
Half-siblings				
Reared	3,144	2.42 (1.1)		95.2 (14.4)
Adopted-away	2,400	2.36 (1.1)	2.70 (1.3)	98.4 (14.6)

results. In another study from France, Schiff et al. (11) reported on 32 children abandoned at birth by their impoverished parents and adopted into homes of upper-middle-class families. The adopted children were compared with 20 biological siblings, who remained with their biological mother. The mean IQ of the adopted group was 110.6, compared with 94.5 in the nonadopted siblings.

In contrast to the reliably positive effects of adoption on the mean IQ of children, when adoption studies are analyzed in terms of correlations between adopted children's IQs and those of their biological and adoptive parents, the correlations with biological parents are invariably higher, indicative of strong genetic effects on cognitive ability (12, 13). Indeed, the two apparently contradictory findings—stronger correlations with biological parents than adoptive parents, but changes in the mean consistent with environmental effects—are often reported in the same study. In Skodak and Skeels' studies, for example, the correlation of children's IQ with their biological parents' IQ was 0.31 at the final testing, whereas the correlation with adoptive-parent IQ did not differ significantly from zero. Reanalysis of the Schiff et al. adoption data showed that the IQ scores of the adopted children were actually more highly correlated with the occupational status of their biological parents than their adoptive parents, despite the significant environmental effect on the mean (4).

Although theorists have sometimes suggested that there are two independent "realms of development," with mean scores influenced by the environment (14), and individual differences around the mean influenced by genes, the contradictory findings belong in the same developmental model, and the apparently contradictory results can be understood as different manifestations of the same underlying processes. If each additional unit on a socioeconomic scale (SES) is associated with 0.7 IQ points, and the adoptive parents of a group of children have a mean SES 10 points higher than the biological parents, then a straightforward linear model of individual and group differences would predict that the adopted children would experience a 7-point increase in IQ. Jensen (15) showed that in Skodak and Skeels' adoption study, the increase in the adopted children's IQ was consistent with a heritability as high as 0.8. Turkheimer (4) reanalyzed results from all adoption studies of IQ available at the time and showed that most effects on means and individual differences could be explained in the same model.

We describe here the largest study to date of IQ in biological siblings separated by adoption. Swedish national registers were searched to identify >2,500 male sibships in which at least one member was adopted away and at least one member was home-reared by the biological parents. Cognitive assessments at military conscription were conducted for all siblings. Data were also available on the educational attainment of both the biological and adoptive parents, allowing the estimation of differential effects of genetic background and rearing environment.

Table 2. Relevant characteristics of the full- and half-sibling samples

Relevant variables	Full-siblings		Half-siblings	
	Adopted	Reared	Adopted	Reared
Parents (biological), <i>n</i>	436	436	2,341	2,341
Adoptive families, <i>n</i>	447	447	2,374	2,347
Age of the parents at birth				
Mother, mean (SD)	26.5 (6.4)	24.8 (5.2)	22.9 (5.5)	26.8 (5.7)
Father, mean (SD)	30.4 (7.4)	28.5 (6.3)	26.4 (6.9)	30.1 (7.0)
Year of birth, mean (SD)	1964 (5.8)	1962 (7.1)	1963 (5.9)	1967 (4.6)

Results

Characteristics of the sample are summarized in Tables 1 and 2. We identified 436 male–male full-sibships in which at least one sibling was home-reared by his biological parents and one reared by an adoptive family. Biological parents were slightly younger at the birth of the home-reared (25.0; SD = 5.4) than of the adopted (27.2; SD = 6.9) child. The mean educational level was significantly higher for the adoptive (2.64, SD = 1.30) than for the biological (2.01, SD = 1.00) parents. The mean educational levels of the biological and adoptive parents were modestly correlated: $r = +0.18$ (SE = 0.05).

The mean IQs of the home-reared and adopted-away full-siblings were 92.0 and 96.9, respectively (Table 1). The IQ scores of the adopted-away full-siblings were correlated +0.20 with the midparent educational levels of their biological parents and +0.18 with the midparent educational levels of the adoptive parents; the IQs of the home-reared siblings were correlated +0.34 with the midparent educational level of their biological parents, who also reared them (Table 3).

We analyzed the results in more detail using a random-effects model that quantified the difference between home-reared and adopted-away children while controlling for the clustering of children within biological families. As summarized in Table 4, we began with a null model (model 1) to establish the degree of familial clustering. We then tested whether the IQ of the siblings was predicted by their adopted-away vs. home-reared status (model 2), controlling for clustering of siblings within biological families. Being adopted away was associated with a 4.41 (SE = 0.75) advantage in IQ compared with siblings home-reared by the biological parents. We next examined a regression model that predicted the IQ scores of the full-siblings from their adoption status and the educational levels of their biological and rearing parents (model 3). The education scores for the biological

Table 3. Relevant correlations of the full- and half-sibling samples

Correlated variables	Correlations (SE)	
	Full-siblings	Half-siblings
IQ–education bio parents (all)	0.28 (0.05)	0.24 (0.01)
IQ–education bio parents (reared)	0.34 (0.04)	0.29 (0.02)
IQ–education bio parents (adopted)	0.20 (0.05)	0.18 (0.02)
IQ–education adoptive parents	0.18 (0.05)	0.18 (0.02)
Education adoptive parents–education bio parents	0.18 (0.05)	0.20 (0.02)

Table 4. Results of random-intercept linear mixed models predicting IQ in adopted and reared full- and half-siblings

Predictor variables	Model 1	Model 2, mean (SE)	Model 3, mean (SE)
Full-siblings			
Adopted-away vs. home-reared		4.41 (0.75)	3.38 (0.79)
Biological parent education			2.73 (0.56)
Rearing parent education			1.71 (0.44)
Share of adopted			
Variance bio parents	59.89	60.81	43.51
Variance individuals	148.61	142.32	141.44
ICC,* %	28.7	29.9	23.5
Half-siblings			
Adopt-away vs. home-reared		3.18 (0.34)	2.70 (0.34)
Biological parent education			1.56 (0.19)
Rearing parent education			1.94 (0.18)
Share of adopted			
Variance bio parents	56.15	57.61	44.15
Variance individuals	160.32	156.38	154.03
ICC,* %	25.9	26.9	22.3

*The intraclass correlation (ICC) reflects how much of the total variation in IQ can be attributed to differences between sibships.

and rearing parents were set to equality for the home-reared children, because these were the same individuals. Results showed that each additional unit of biological-parent education was associated with 2.73 (SE = 0.56) units of IQ in the offspring, averaging across the adopted-away and home-reared siblings; each additional unit of rearing parental education was associated with 1.71 (SE = 0.44) units of IQ, and adopted-away siblings had an additional average 3.38 (SE = 0.79) IQ point advantage over their home-reared siblings, after accounting for parental education differences.

Model 2 also provides estimates of the random variances attributable to clustering in biological families and differences within biological families. Ratios of these variances can be used to compute the intraclass correlation among biological full-siblings, equal to +0.30. We note that this correlation is an amalgam of genetic and family environmental variability, because in some families, more than one sibling was reared by the biological parents. As a result, covariance among biological siblings is a combination of genetic and rearing effects.

The effect of adoption was linear and additive across the range of biological and adoptive parent education, including offspring adopted into families whose parents had lower educational levels than their biological parents. Fig. 1 illustrates the magnitude of the IQ difference between adopted and nonadopted full-siblings as a function of the difference in education level between the biological and adoptive parents of the adopted siblings. At one extreme, in families where the mean adoptive parental educational status was at least 2.5 steps higher than biological parental educational status (i.e., the difference between no high school and some postsecondary education), the adopted-away sibling had an IQ that averaged 7.6 points higher than his home-reared adopted sibling. At the other extreme, in the sibling sets in which the biological parental educational status was at least 2 steps higher than that of the adoptive parents, the adopted-away sibling had an IQ that was on average 3.8 points lower than his home-reared sibling.

We replicated these results in a sample of 2,341 male half-siblings (sharing a single parent) from the same population (Table 1), using the same sequence of models. The mean IQs of the home-reared and adopted-away half-siblings were 95.2 and

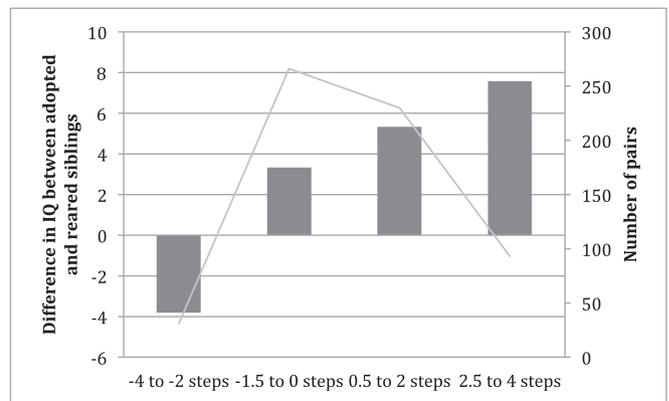


Fig. 1. Magnitude of IQ difference (black bars and left y axis) between adopted and nonadopted full-siblings as a function of the difference in educational level between biological and adoptive parents of the adopted siblings (x axis). The four bars represent (from left to right) -4 to -2 steps; -1.5 to 0 steps; 0.5-2 steps; and 2.5-4 steps difference on the education scale. The gray line (right y axis) illustrates the number of pairs in each group.

98.4, respectively (Table 1). As shown in Table 3, the IQ scores of the adopted-away half-siblings were correlated +0.18 with the mean educational levels of their biological parents and +0.18 with the mean educational levels of the adoptive parents; the IQs of the home-reared half-siblings were correlated +0.29 with the mean educational level of the biological parents who reared them. Model 1 quantified the clustering of offspring in biological families. Model 2, assessing the effect of adoption status controlling for clustering within biological families, showed that being adopted away was associated with a 3.18 (SE = 0.34) point advantage compared with the home-reared half-siblings. Model 3 predicted offspring IQ from adoption status, educational level of the biological parent shared by the half-siblings, and mean education of the adoptive parents. Results were similar to those for the full siblings. Each additional unit of biological parent education was associated with 1.56 (SE = 0.19) units of IQ in the offspring, averaging across the adopted-away and home-reared siblings; each additional unit of rearing parental education was associated with 1.94 (SE = 0.18) units of IQ in the adopted siblings; and the adopted-away siblings had an additional 2.70 IQ (SE = 0.34) point advantage over their home-reared siblings after accounting for differences in rearing parental education.

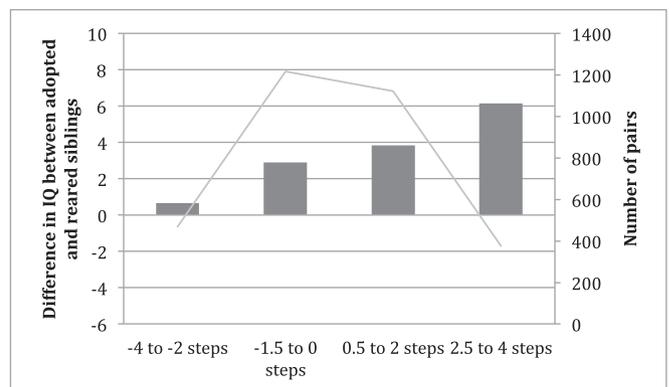


Fig. 2. Magnitude of IQ difference (black bars and left y axis) between adopted and nonadopted half-siblings as a function of the difference in educational level between biological and adoptive parents of the adopted siblings (x axis). The four bars represent (from left to right) -4 to -2 steps; -1.5 to 0 steps; 0.5-2 steps; and 2.5-4 steps difference on the education scale. The gray line (right y axis) illustrates the number of pairs in each group.

The intraclass correlation for IQ among half-siblings was +0.27. Fig. 2 illustrates the magnitude of the IQ difference between adopted-away and home-reared half-siblings as a function of the difference in educational level of the biological and adoptive parents. In families where the mean adoptive parental educational status was at least 2.5 steps higher than biological parental educational status, the adopted-away half-sibling had an IQ 6.1 points higher than his home-reared half-sibling. By contrast, when the biological parental educational status was at least two steps higher than the adoptive parents, the adopted-away sibling had an IQ that averaged only 0.6 points higher than his home-reared half-sibling.

In both the full- and half-sibling samples, we examined an interaction between adoption status and mean biological-parental education that would account for a stronger relationship with IQ in the home-reared children (to whom the biological parents provided both genes and rearing environment) than for the adopted-away children (to whom they only provided their

genes). This interaction did not approach significance in either sample. We also examined a term accounting for the number of adopted children biological parents contributed to the sample. Although families contributing more adoptees had offspring with slightly higher IQs, inclusion of this variable produced no substantial changes in other parameters of the model.

Discussion

The present study contributes to our understanding of the environmental malleability of cognitive ability. We have shown in a population-based sample at least an order of magnitude larger than any previous study that the IQs of adopted-away individuals are higher than those of their matched full-siblings reared in their home environment. We replicated these findings in an independent sample of half-siblings. Differences among the intellectual abilities of the adopted-away and home-reared siblings showed expected relations with the educational status of their biological and, in the adopted offspring, rearing parents. In

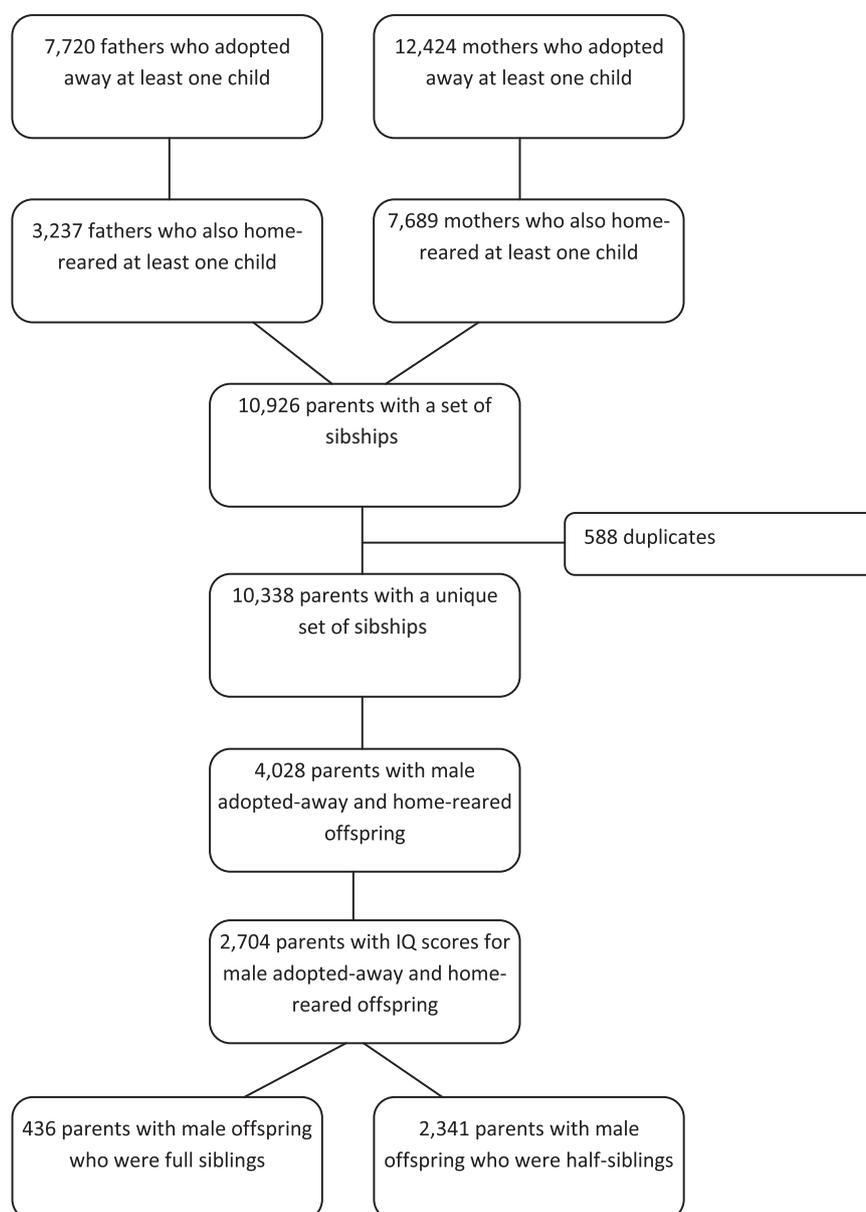


Fig. 3. A flowchart showing the creation of the full- and half-sibling databases.

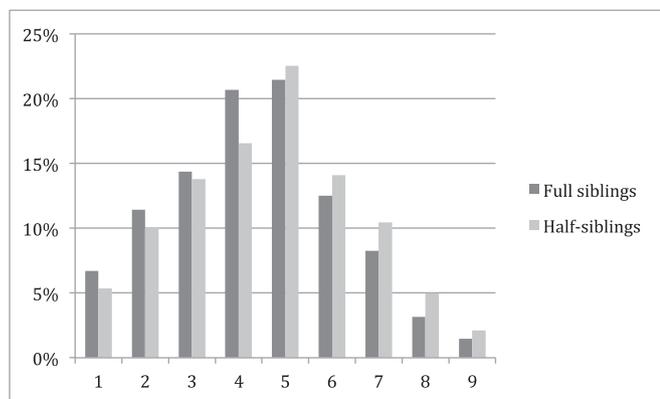


Fig. 4. The distribution of the standardized IQ score in the full- and half-sibling samples.

particular, relations with adoptive-parent education behave exactly as one would expect if rearing environment had a causal effect on ability: Offspring placed in the best-educated homes had the highest scores, whereas those placed in homes less educated than the family of origin actually performed worse than their nonadopted siblings.

We emphasize that our demonstration of the environmental malleability of cognitive ability is fully consistent with coexisting genetic influences. Indeed, although the separated-sibling design is especially well-suited to studying the effects of the family environment, the correlation between the education levels of biological parents and the cognitive ability of their adopted-away children and the intraclass correlation among biological siblings reared apart are both indicative of substantial genetic effects in this sample. Our goal in this study was not to exclude genetic explanations, but rather to control for them while focusing on a natural experiment involving differences in environmental experiences.

Although the 2- to 5-IQ-point advantage in the adopted-away children is smaller than differences reported in earlier and smaller studies, it is important to bear in mind that the environmental difference between the adoptive and biological families was not especially large, compared with earlier adoption studies that intentionally sampled children from extremely deprived backgrounds. The adoptive parents were, on average, better educated than the biological parents (16), but the biological families were not selected for deprivation; although the adoptive families were screened by the adoption agency, the full population of adoptive families was used in the analysis, rather than selecting those families that provided the greatest environmental enrichment. Moreover, the population under study was in Sweden, where extremes of poverty and wealth are relatively rare.

Our analysis showed that, among the biological parents, each additional unit on the parental education scale was associated with 2.7 IQ points in the child, whereas among the adoptive parents, each additional unit of education was associated with 1.7 IQ points. Taking results from Table 1, the adoptive and biological parents differed by $\sim 2.6 - 2.0 = 0.6$ points on the education scale. Therefore, the model predicted that $1.7 \times 0.6 = 1.02$ of the observed IQ difference between the home-reared and adopted-away children would be explained by the difference in parental education. Comparison of models 2 and 3 in Table 4 shows that this is the case: The residual difference between the IQs of the two groups of children was reduced from 4.4 to 3.4 when the difference between the biological and rearing parents' education was included in the model. We emphasize that the best estimate of the IQ change resulting from the adoption

remains 4.4 IQ points; the reduced figure is just an estimate of how much of that difference can be explained by measured differences in parental education.

The analyses of previous adoption studies in Turkheimer (4) suggest that our findings are typical of unified analyses of adoption studies. Parental education is an imperfect indicator of environmental quality. Although one would expect children placed with the best-educated parents to show the greatest increases in IQ, one would not expect it to explain all of the observed difference. In addition, there may be different constraints on the variances of the environment within and between groups of adopted children (16). In comparisons of biological and adoptive families, the environmental variance is enhanced by the contrast between these relatively disparate groups, making between-group environmental differences easier to detect.

Results of studies of changes in cognitive ability that result from environmental manipulation are sometimes discussed in terms of either relative contributions of genes and environment or how much IQ can be raised by an environmental intervention. We prefer a perspective that uses a genetically informative design to estimate the magnitude of environmentally mediated IQ gains as a function of the nature of the environmental change, including the level of the original deprivation and the magnitude of the eventual enhancement. This point of view has been represented in terms of a construct called a reaction norm, in which the development of a phenotype is viewed as the results of the joint effect of genetic and environmental differences, with neither being granted causal priority (17). Despite being demonstrably related to genetic endowment, cognitive ability is environmentally malleable, and the malleability shows plausible dose-response relations with the magnitude of the environmental differences.

Materials and Methods

We used data from multiple Swedish nationwide registries linked by the unique individual Swedish 10-digit personal ID number assigned at birth or immigration to all Swedish residents. This ID number was replaced by a random number to preserve confidentiality. Our database was created from the following sources: the Total Population Register, containing annual data on family status; the Multi-Generation Register, providing information on family relations; the Military Conscription Register, which includes cognitive assessments for nearly all 18-y-old men in Sweden; the Population and Housing Censuses that provided information on household status and educational status in every fifth year between 1960 and 1985; and the Longitudinal Integration Database for Health Insurance, which contains yearly assessments of education for all individuals 15 y or older since 1990. We secured ethical approval for this study from the Regional Ethical Review Board of Lund University.

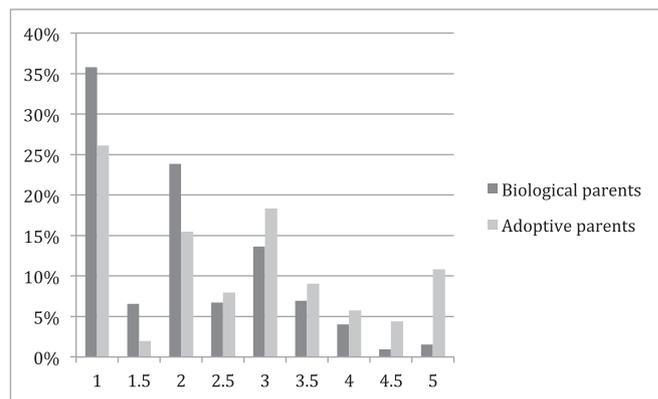


Fig. 5. The distribution of the mean educational level of biological and adoptive parents in the full-sibling sample. The five levels indicated on the x axis are: (1) <9 y, (2) 9 y, (3) 10–11 y, (4) 12 y, and (5) >12 y.

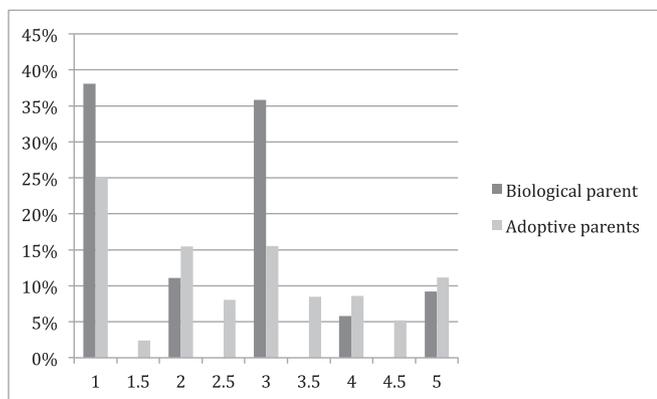


Fig. 6. The distribution of the educational level of biological and adoptive parents in the half-sibling sample. The five levels indicated on the x axis are: (1) <9 y, (2) 9 y, (3) 10–11 y, (4) 12 y, and (5) >12 y.

As outlined in Fig. 3, the full- and half-sibling databases were created by entering all full- and half-sibling sets born between 1955 and 1990, for which at least one of the siblings within the family was adopted before age 5 and at least one of the other siblings resided, for a minimum of 10 y, in the same household as their biological mother and/or father.

Age at formal adoption was not available in National Records until 1991. We therefore could only set an upper limit on the true age at adoption from census data available every fifth year. Other sources indicate that during this time period, because private adoptions were prohibited by Swedish law, children were taken into institutional care by the municipalities shortly after birth and adopted at a median age of 6 mo, with very few children adopted after 12 mo of age (18, 19).

Siblings adopted by biological relatives or by an adoptive parent living with a biological parent were excluded. The full-sibling database included 590 home-reared individuals and 453 adopted-away individuals (into 447 adoptive families) nested within 436 biological parents. The corresponding figures for half-siblings were 3,144 home-reared, 2,400 adopted-away (into 2,374 adoptive families), and 2,341 biological parents. In the half-sibling database, 21% of half-siblings could not be linked to a biological father. Further details of the full- and half-sibling samples are shown in Tables 1 and 2.

Adoptive parents are carefully screened in Sweden for their ability to provide a high-quality rearing environment (18). Because the number of

children available for adoption has been considerably smaller than the demand, the selection process is rigorous. Bohman notes that this process in Sweden was designed to “assess the general health, personality, and mutual relationship of the presumptive adoptive parents” with the goal of forecasting “the durability of their marriage... [and] place the child in an harmonious, stable environment...” (ref. 18, p. 87).

The Swedish military service conscription examination involves a full medical assessment including cognitive function (IQ) measured by four subtests representing logical, spatial, verbal, and technical abilities. During the years covered by this study, this examination was required by law; only men of foreign citizenship or those with a severe medical condition or disability were excused. The global IQ score, derived from a summation of the four subtests, was standardized to give a Gaussian distributed score between 1 and 9, the distribution of which is seen in Fig. 4. We translated this score into IQ units with a mean of 100 and SD of 15. Educational status among biological and adoptive parents of full-siblings and the adoptive parents of the half-siblings was measured as the mean of the highest education achieved by both parents, was categorized into five groups [(1) <9 y, (2) 9 y, (3) 10–11 y, (4) 12 y, and (5) >12 y] and treated as a continuous variable. For half-siblings, we only examined the educational status of the shared biological parent. The distributions of the educational levels of biological and adoptive parents in the full- and half-sibling samples are shown in Figs. 5 and 6.

Statistical analyses consisted of a series of random-intercept linear mixed models, with individuals as the level-1 unit, biological parents the level-2 unit, and IQ as the outcome. The random intercept model provides a subject-specific regression coefficient for adopted-away vs. home-reared adjusted for the familial cluster and therefore accounts for shared genetic factors. Statistical analyses were performed by using PROC MIXED in SAS (Version 9.3).

Characteristics of the sample are summarized in Table 1. We identified 436 male–male full-siblings in which one sibling was home-reared by his biological parents and the other reared by an adoptive family. Biological parents were slightly younger at the birth of the home-reared (25.0, SD = 5.4) than of the adopted child (27.2, SD = 6.9). The mean educational level was significantly higher for the adoptive (2.64, SD = 1.30) than for the biological (2.01, SD = 1.00) parents. The mean educational levels of the biological and adoptive parents were modestly correlated: $r = 0.18$ (SE = 0.05).

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