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SOCIAL AND GENETIC EFFECTS ON EDUCATIONAL PERFORMANCE IN EARLY ADOLESCENCE

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ABSTRACT

Research into the intergenerational transmission of educational advantage has long been criticized for not paying sufficient attention to genetics. This study is based on the Norwegian Mother, Father and Child Cohort Study (MoBa) and administrative register data on 25000 genotyped Norwegian children and their parents. We assess and disentangle the relative importance of genetics and social background for children's standardized academic test scores. Norway offers a particularly interesting context for intergenerational transmission, as the welfare state and educational system is designed to provide equal opportunity structures for children. The results point to genetics only confounding the parent status-offspring achievement relationship to a small degree, to 'genetic nurture' effects being small, and pro-vide no evidence of neither Scarr-Rowe interactions in test scores nor parent-child genotype interactions. Even in a universal welfare state with relatively low levels of inequality, there are two systems of ascription, one genetic and one social, and these are largely independent of each other.

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INTRODUCTION

An abiding interest of social scientists is the extent to which successful parents transmit social advantages to their children (Blau and Duncan 1967; Lareau 2011). A well-established research literature has shown that such transmission of advantage takes place in industrialized societies despite the hypothesized waning importance of ascription, and that the educational system is at the center of these transmission processes (Breen and Jonsson 2005). Researchers have considered a wide range of different factors and mechanisms possibly involved in generating the relatively higher achievement and attainment of children of more educated parents, such as family income for purchasing of educationally-relevant goods (Teachman 1987), relative risk aversion (Van de Werfhorst and Hofstede 2007), parenting styles (Roksa and Potter 2011), cultural capital (Jæger 2009, 2011), and school quality (Duncan and Murnane 2014).

By and large, social and economic research has emphasized social explanations as to how the effect of family background on educational outcomes emerges. That the social influence of family background may be confounded by genetics has been known for the better part of the last century (Burks 1928; Eckland 1967; Marks 2013). Yet, most social scientists studying intergenerational transmission have not availed themselves of genetically informed data and research designs. The large literature from behavior genetics has shown that nearly every individual-level outcome of interest is heritable to some degree (Freese 2008; Polderman et al. 2015; Turkheimer 2000). Social scientists' relative lack of interest in genetics and its potential role as confounder, moderator or mediator of social effects may be due to lack of access to such data, a tradition for skepticism to biological explanations in general, or more specific doubts about the validity of genetically informed designs such as twin studies.

Until fairly recently, most genetically informed designs available to social scientists were twin designs or similar designs that predicated on indirectly inferring genetic relatedness from pedigrees. Now, with technological advances in genetics and a rapidly increasing availability of genetic data, some scholars have argued that we are entering a new age of "sociogenomics" – the combination of genetics and social science (Conley and Fletcher 2017; Freese 2018; Mills and Tropf 2020). At any rate, social scientists are becoming increasingly aware of the role genetics may play in intergenerational transmission processes. A small, but growing soci-

al science literature using direct measurements of genetics to study educational outcomes has emerged (see e.g. Conley et al. 2015; Belsky et al. 2016; Liu 2018). These studies have exploited recent advances in molecular genetic methods and measurement to assess the role of genetic confounding of parental influences on educational attainment using polygenic scores, summary measures of an individual's genetic dispositions for a trait. The results thus far have allowed genetics a role in adult educational attainment, but not found support for strong genetic confounding of the relationship between parents' education (or SES) and children's own education in adulthood. Mechanisms that are suggested to produce intergenerational correlations in educational outcomes should, however, chiefly operate in life stages earlier than adulthood, as admissions to higher education at least partly are decided on the basis of earlier achievement. There may also be interactions between a child's genetic dispositions and the parent's social and genetic characteristics. One type is the the Scarr-Rowe interaction where lower SES family environments led to suppression of heritability (Scarr-Salapatek 1971; Turkheimer et al. 2003), another is the possibility of genotype-genotype similarities, where relationships between children and offspring with above-average genetic similarity are particularly conducive of learning. Understanding the role genetic dispositions of parents and children in how how such effects come about is a prime interest to researchers in the stratification, family, and genetics fields alike.

Most contributions to the existing literature in the genetics–social stratification field analyze data from the United States or the United Kingdom. These societies have relatively high levels of inequality and provision of education is less standardized. In contrast, we analyze data from Norway, a fairly egalitarian context with a universal school system with very few students attending private schools, relatively low variations in school quality (Hermansen, Borgen, and Mastekaasa 2020), and a strong social welfare system (Esping-Andersen 1999). All these factors could in principle reduce the importance of parents' social characteristics on test scores because children are provided with more equal opportunities, and those opportunities are to a lesser extent than in most other societies a function of their family background. Norway represents an interesting contrast on the political economy dimension to the US and UK studies, where both inequalities in the school system and the intensity of social stratification are generally higher.

The present study offers several contributions to the literature. We estimate genetic and social intergenerational effects on educational achievement using the one of the largest genetic-trio datasets with measured genotypes of both parents and offspring available, the Norwegian Mother, Father and Child Cohort Study

(MoBa, Magnus et al. 2016). Using the latest iteration of educational attainment GWAS based on 1.1 million people (Lee et al. 2018) to create a polygenic score for education for each family member, and linked data from administrative register data, we study social and genetic effects on children's educational performance. Our focus is on children's achievement scores on standardized tests in Reading (Norwegian), English and Mathematics, taken in the 5th, 8th and 9th grades. We first establish the extent to which associations between parents' education and children's educational achievement, i.e. their test scores, are confounded by the children's own genotypes. We then consider whether the mechanisms behind parental education effects on test scores stem from parents' own genetic profiles, or operate largely independently of them. Third, we examine any interactions between child genotype effects and parents' education, as suggested by the literature on the Scarr-Rowe interaction. Finally, we test the existence of parent-child genotype interactions, where genetic dispositions towards education in parents and their child produce a synergy effect for educational achievement as has been suggested for the US context (Conley et al. 2015).

EDUCATION, INTERGENERATIONAL TRANSMISSION, GENES AND ENVIRONMENTS

Education is at the center of human development goals, and a crucial factor in social mobility (Bernardi and Plavgo 2020). Social science classics have centered on the intergenerational transmission of education from parents to children (e.g. Boudon 1974) The explanations offered by social scientists for such transmission have for the most part been rooted in social mechanisms: parents' education or socioeconomic status having a causal influence on children's achievements and attainments–meaning that if we manipulated one generation's education levels through a policy lever or other environmental change, we would observe the parameter estimate change in measures of the next generation's achievement and attainment. There is a large catalog of mechanisms suggested contributing to the link between family socioeconomic status and children's educational achievement (Fergusson, Horwood, and Boden 2008). This large body of work show that parental socioeconomic status is a strong predictor of children's educational achievements and a big part of children's cultural inheritance. But of course, children do not only inherit their parents' cultural resources, but also their genes, potentially confounding such social explanations.

Indeed, studies in the behavioral genetics tradition have shown that a large

part of the correlation between twins is due to shared genetics, rather than sharing or inheriting social resources for a vast array of outcomes (Polderman et al. 2015). The workhorse of behavioral genetics is the ACE model, i.e. the classical twin study of siblings reared together. The ACE model leverage the different degrees of genetic relatedness between monozygotic and dizygotic twins, their siblings and parents to estimate the variance of latent variables for genetic and environmental influences on outcomes. The method indirectly partitions the outcome variance into three components: Additive genetics (the narrow-sense heritability coefficient, often just mentioned as heritability), common environmental influences (the variation that is shared between twins/siblings) and non-shared environmental influences (including measurement error). Genetic propensities are always mediated through environment in some way or other, so these heritability estimates vary across time, place and social organization (Engzell and Tropf 2018; Rimfeld et al. 2018). On average, twin studies of educational attainment show fairly consistently a considerable heritability, hovering around 40 % (Branigan, McCallum, and Freese 2013; Silventoinen et al. 2020). Contrary to what is typically the case in twin studies of other types of outcomes (Polderman et al. 2015), common environmental influences are also found to be high, explaining around 30-40 % in the variance. As the common environmental influences component include all environmental exposures influencing twin similarity, it encompasses parental socioeconomic status, parenting styles not varying across siblings, similarity in school environments, and more. Twin studies on educational achievement in adolescence show an even higher heritability, and lower common environment influences than for adult educational attainment (de Zeeuw, de Geus, and Boomsma 2015; Nielsen 2006; Pokropek and Sikora 2015), yet clearly both genes and common environments play a role in children's performance.

Whereas classical social scientific studies are vulnerable to confounding by genetic inheritance, the behavioral genetics field has been criticized for not measuring genetics directly, and on the assumptions required to underpin twin and pedigree research designs (Barnes et al. 2014; Daw, Guo, and Harris 2015, but see Conley et al. 2013 for empirical support of the assumptions; Felson 2014). With scientific advances in genome sequencing and measurement, social scientists now have access to new tools for investigating social and genetic effects on their outcomes of interest (Conley 2016; Freese 2018). Important tools in the emerging field of sociogenomics are genome-wide association studies (GWAS) and their resulting composite: polygenic scores (PGS). A GWAS is a data-driven statistical search for associations between and a outcome and genetic variants at the molecular level of the type single-nucleotide polymorphisms (SNPs), the vari-

ants that are most common in the population. Using large samples, standardized measurements and strong standards of statistical significance to account for multiple testing across the genome, a large number of GWAS's have found correlations between SNPs and many outcomes of interest to social scientists, such as fertility (Barban et al. 2016) and educational attainment (Lee et al. 2018; Okbay et al. 2016). Based on the results from GWASs, one can construct polygenic scores, measures that aggregate all or many genetic associations for a trait into a single score for each individual in an independent sample. Importantly, PGSs are based on direct measurements of genetic variants which can be constructed using unrelated individuals, and therefore it does not rely on indirectly modelling genetic relatedness such as in twin studies.

Polygenic scores are a useful step forward in assessing the influence of genotypes on phenotypes (traits) such as education (Ayorech et al. 2017). As the genetic makeup of an individual is fixed at conception and does not change later in life, PGS' offer a tool to disentangle genetic and environmental influences on education, based on direct measurements of genetic variants. PGSes are, however, far from a panacea, as they may pick up environmental variation too (Cheesman et al. 2019), caused by population stratification, dynastic effects, and assortative mating (Morris et al. 2020). There are numerous statistical applications which may alleviate some of the environmental confounding of the PGS', and the current gold standard is using family-based samples (Young et al. 2019). Trios are family-based samples where offspring and their parents are genotyped. In addition to its use for removing environmental confounding, trios allow for investigating genetic and environmental intergenerational pathways of particular interest to social scientists (Koellinger and Harden 2018; Mills and Tropf 2020). One such pathway is the effect of parental genomes on children's outcomes through environmental pathways, in the genetics literature known as "genetic nurture" (Bates et al. 2018; Conley et al. 2015; Kong et al. 2018). Researchers have established that there are effects on offspring educational outcomes of parents' genetic variants that were not transmitted to the offspring at conception. Such effects can only by mediated environmentally as there are no direct genetic pathways left when children PGS' are included in the model.

With the increase in availability of genomic data sources, a small, but growing social scientific literature has emerged that links genomic measures, such as polygenic scores, to educational outcomes. One study found parents' education to be more important than genetics for the intergenerational transmission of educational attainment. In a study from the United States, around 1/6 of the intergenerational correlation was due to shared genetics (Conley et al. 2015), leaving a sizable

social background component. Liu (2018) used data on three generations and the latest iteration of the educational attainment GWAS to assess effects of parents' and grandparents' characteristics on adult educational attainment in a multigenerational design applied to the same data as Conley et al. (2015). Here, coefficients for parent's education, child's PGS and parents' PGSs are all significantly associated with children's educational attainment, i.e. documenting "genetic nurture" effects. The effect of child's PGS far outweighs the genetic nurturing effect of parent's untransmitted PGS. Parents' (phenotypic) educational attainment is still the most important variable, with genetics confounding the intergenerational association by around 1/5.

Much of the social science genetics literature has considered adult educational attainment, and the literature on educational achievement in childhood and adolescence is markedly smaller. The few existing studies with genomic data have mostly supported the idea of two ascriptive systems. Using the UK BioBank data, von Stumm et al. (2020) examined the role of the educational attainment PGS as a predictor of educational achievement at differerent child ages, and found that a child's genetics and mechanisms related to the family's socioeconomic status operated largely independently of each other. A recent study of cognitive and brain development with data from the UK, Germany, France and Ireland found that higher socioeonomic status was associated with global changes in brain during adolescence and suggested that the educational attainment PGS and family socioeconomic status operates largely independent of each other (Judd et al. 2020). Using UK data, Morris et al. (2020) found that effects of a PGS on educational achievement measures were attenuated by around 1/3 when controlling for both mother's and father's genotypes. The heritability was attenuated by around half of the original effect when controlling for parents' years of education. Thus, both the child's own genetics and the genetics of the parents were found to shape educational achievement. A recent review of "genetic nurture" studies concluded that most genetic nurture effects operate through the parental phenotypes, i.e. their own educational attainment (Wang et al. 2021). With two exceptions, the reviewed studies all used data from liberal welfare state countries (Wang et al. 2021).

The Context

Our data are drawn from the Norwegian survey and administrative register data. This particular context has important implications for our empirical expectations. Norway is a wealthy Scandinavian welfare state, with a long history of acti-

ve policies towards reducing social disparities, providing a universal social safety net, and expanding opportunity structures for all. The welfare state weakens the impact of various life course events that otherwise would be harmful for the child's parents, such as unemployment and illness.

The educational system also has features that shapes our expectations. Most Norwegian kids attend the local public school. Funding for schools vary little across communities, and so does curricula and teaching staff qualifications. There are no tuition fees in the public system. The share of students attending private schools is very small, and these schools are typically international schools, offer special pedagogical programs, or athletic programs and all are strictly regulated by the government to comply with various national standards. For the parents, there are several societal factors that contribute to opening opportunity structures for attaining educations. The State Educational Loan Fund offer universal financial assistance for both secondary diplomas and tertiary degrees, there are degree-granting tertiary institutions spread around the country. The educational system is also quite flexible, and credits can easily be transferred between institutions and programs. The influence of one's family of origin on one's educational decision-making may be lower than in e.g. the United States, leading to a higher concordance between ambitions, motivation and talent on the one hand and actually attained education on the other.

What are the implications of these societal features, a wide social safety net and an egalitarian oriented educational system, for our analysis? For one, we expect to find the degree of genetic confounding in Norway to be larger than what is found in more market-oriented societies such as the United States. Second, we expect to find weak or no Scarr-Rowe interactions, as the institutional differences should make life less precarious for parents and level the playing field with benefits for children from disadvantaged families in countries like Norway.

Possible interaction effects

Thus far, we have only considered separate additive effects of socioeconomic status and genetics on educational achievement. Gene-environment correlations add another layer of complexity. An important entry point to GxE-correlations has been the seminal work by Sandra Scarr (1971), leading to what has become known as the Scarr-Rowe hypothesis. This idea posits that family socioeconomic status affects the realization of offspring's intellectual potential, and that as a consequence the variance explained by genetics is lower in families with lower socioeconomic status. The original hypotheses linked poverty and serious econo-

mic deprivation to intelligence, but the hypothesis has inspired a whole literature considering social gradients in genetic effects in not only cognitive outcomes but also school performance and adult educational attainment (Baier and Lang 2019). Results consistent with the hypothesis has been found in a highly cited study of twins from the United States (Turkheimer et al. 2003),

Generally, the empirical support for Scarr-Rowe-derived hypotheses in educational achievement is mixed, and a large study using administrative data on same-sex twins from Florida found no support for the hypothesis (Figlio et al. 2017). Conley et al. (2015) found no corresponding gradient in the PGS predicting educational attainment, but the available data were limited in sample size and the PGS predictive power was low relative to the present study.

Finally, the mechanisms linking family socioeconomic status and children's educational achievement typically involve parents and children interacting, as when parents help children with homework, support them financially or in other ways improve environments. A dimension of these interactions that thus far has garnered very little attention is the possibility of genotype-genotype interactions. A parent and child can be more or less similar in their genetically anchored dispositions for education. Such similarity could in principle lead to a synergy effect emerging from parent-child interactions. The synergy effect would mean that a child's educational achievement would be higher if both the parents and the child have high polygenic scores for education. Little is known about such genotype-genotype interactions, but a recent paper point towards the opposite situation, wherein there evinces compensating effects of more intense parenting if one sibling has a lower PGS than the other (Fletcher et al. 2020).

Study aims and analysis plan

The aim of this study is to improve our understanding of the role of parents' influences and the importance of genetics and social advantages by modeling the relationships between child's genotype, parents' genotypes, and parents' educations one the one hand and child educational performance outcomes, on the other hand, across three stages of adolescence. The target population is children born in Norway 1999-2008, and our main quantities of interest are the direct effect of child's genotype, the total effects of parents' genotype, and the conditional effect of parents' education given child's genotype.

We are able to contribute to the literature in several ways. First, the sheer size of our sample, more than 26000 families, is larger than the largest of recently reviewed studies with "genetic nurture" designs, and in contrast to many previous

studies we have genotype information on children and both parents. This provides much more statistical power than previous studies. Second, some of the previous studies are based on iteration one or two of the educational attainment GWAS series. We use the latest iteration, which improves PGS' predictive power considerably (the EA PGS R^2 has gone from 3% through 7% to 13%-15%). Third, very little work has been done on educational achievement in adolescence using such data. Most studies study educational attainment in adulthood, but our study address genetic and environmental intergenerational transmission processes earlier in the life course, around ages 10 through 15. Fourth, we examine intergenerational transmission in a different social context than most recent studies. Most of the genetically informed literature uses data from the United States (e.g. the Health and Retirement Study) or other liberal welfare states countries (e.g. the UK BioBank). Norway is a Scandinavian welfare state, where policies have explicitly targeted transmission of intergenerational inequalities, and sought to limit the influence of family background on children's outcomes and opportunities. Little research using molecular genetic data has been conducted thus far in social democratic welfare states such as Norway (but see Kong et al. (2018) for an exception wtih data from Iceland). Fifth, we test whether there are interactions between parents' educational attainments and genetics and child's genetics, probing the existence of both Scarr-Rowe-type mechanisms (Scarr-Salapatek 1971) and genotype-genotype interactions (Conley et al. 2015).

DATA

The data used in the study were assembled from two different data sources: the Norwegian Mother-Father-and-Child Study (MoBa) and register data from several Norwegian national administrative registration systems. MoBa is a population-based pregnancy cohort study conducted by the Norwegian Institute of Public Health (Magnus et al. 2016). Participants were recruited from all over Norway from 1999-2008. The women consented to participation in 41% of the pregnancies. The cohort now includes 114.500 children, 95.200 mothers and 75.200 fathers. The current study is based on version 12 of the quality-assured data files. The establishment of MoBa and initial data collection was based on a license from the Norwegian Data Protection Agency and approval from The Regional Committees for Medical and Health Research Ethics. The MoBa cohort is now based on regulations related to the Norwegian Health Registry Act. We obtained genetic data on the children and their parents through MoBa Genetics v1.0, an infrastructure for

genomic data in MoBa. Blood samples were obtained from both parents during pregnancy and from mothers and children (umbilical cord) at birth. The genomic data were used to calculate polygenic scores for children and their parents within each family.

The register data were collected from several different administrative registers (Lyngstad and Skardhamar 2011; Røed and Raaum 2003). Basic demographic data and kinship links are taken from the Norwegian central population register, and both information on parents' education and children's results on national standardized tests are taken from the National Educational database (NuDB). The linkage between MoBa and register sources was done using the Norwegian national ID number system , with minimal loss of information. The register data generally suffer no attrition and little, if any, error in registration.

Variable definitions

Parents' education Both parents' educational attainments were taken from register data. The data on educational attainment cover the years 1970 and 1980-2018. We choose the measure that is closest in time to when the parents were aged 30. Originally coded on the NUS2000-standard, a taxonomy of educational programs similar to ISCED (Barrabés and Østli 2016), the levels were converted to the expected number of years needed to achieve that level and then z-standardized.

Polygenic scores for educational attainment (EA3) We use polygenic scores for both the child and the parents. The scores are based on the results from the 3rd version of the educational attainment GWAS (Lee et al. 2018). From the available SNP data, polygenic scores were calculated under standard procedures (Mills, Barban, and Tropf 2020), using the PRSice software (Choi, Mak, and O'Reilly 2020). After removing SNPs in linkage disequilibrium by clumping, we use information from all available SNPs when calculating the scores (i.e. a p-value threshold of 1.00). Documentation on the quality control and filtering of SNPs for creating the polygenic scores are included in the supplementary materials. During this process, approximately 5% of the genotyped samples were excluded. Finally, the scores were Z-standardized separately for each role (mothers, fathers, children).

Scores from National Standardized Tests The outcome variables are individual student scores on national standardized tests. As of 2007, all students in Norway are supposed to take nationwide standardized tests in mathematics, reading

comprehension and English (Utdanningsdirektoratet 2010). All three tests are administered in 5th, 8th, and 9th grades, while English is administered in 5th and 8th grade only. The youngest children in our sample have not passed through all three grades, which implies that the number of children with valid observations vary over these test outcomes. We have z-standardized the scores within each test and year combination, so that our outcome variables measure where in the distribution of scores the student places within his/her own cohort on a specific test. The supplement show the distributions of the outcome variables (figure S1).

Common control variables In all models, we include a set of common control variable. We include the child's birth cohort as dummy variables (to absorb any secular trend) and, when using the full sample, the child's sex. We also include a few technical variables from the genotyping process, that are conventional to include when using polygenic scores and necessary for correctly interpreting the results for the scores. These variables are the ten first principal components of the SNP genotype dataset and categorical variables indicating which batch of biological samples that were genotyped (for more details on using genotype data cf. for example Mills et al. 2020).

The Analysis-Ready Sample

Our sample is delineated in several ways. The final sample consists of participant families from MoBa – children and their parents – who meet the following criteria. First, both parents must have consented to participate in MoBa and must all have been genotyped. The second criterion we use is that the child and both parents must have a valid polygenic score, i.e. that their genotype information is complete enough to produce a score. Third, the child must have a valid result on at least one of the set of eight standardized test scores we study. The basic demographic information and polygenic scores have no missing information after these criteria are applied. After all the criteria are applied, we are left with 26518 complete child-mother-father trios in the sample ready for analysis.

Descriptive statistics

Variable	N	Mean	Std.Dev.	P25	Median	P75
Math 5th	24730	0.24	0.98	-0.50	0.30	0.97

Variable	N	Mean	Std.Dev.	P25	Median	P75
Math 8th	12771	0.22	0.96	-0.51	0.24	0.97
Math 9th	8693	0.22	0.94	-0.43	0.33	0.96
Reading 5th	24438	0.24	0.97	-0.46	0.37	1.02
Reading 8th	12745	0.21	0.97	-0.49	0.30	0.98
Reading 9th	8726	0.22	0.93	-0.36	0.39	0.99
English 5th	24536	0.08	0.98	-0.69	0.05	0.88
English 8th	12691	0.10	0.98	-0.72	0.17	0.91
Child's YoB	26518	2005.48	1.89	2004.00	2006.00	2007.00
Father's YoB	26514	1972.48	5.40	1969.00	1973.00	1976.00
Mother's YoB	26518	1974.93	4.71	1972.00	1975.00	1978.00
Child's PGS	26518	0.00	1.00	-0.67	0.00	0.67
Mother's PGS	26518	0.00	1.00	-0.67	-0.01	0.67
Father's PGS	26518	0.00	1.00	-0.68	-0.01	0.67
Father's education	26369	14.14	2.93	12.00	14.00	16.00
Mother's education	26419	14.79	2.64	12.00	16.00	16.00

Data availability and replication This work was approved by the Norwegian National Center for Research Data, the Regional Committee on Medical Ethics, data owners and Statistics Norway.Norwegian privacy regulations limit our ability to share our register data, and the consent given by the MoBa participants does not open for storage of data from MoBa on an individual level in repositories or journals. Individual researchers may apply to obtain permissions and subsequently access the data. Researchers who want access to MoBa data sets for replication should submit an application to datatilgang@fhi.no. Access to data sets requires approval from The Regional Committee for Medical and Health Research Ethics in Norway and an agreement with MoBa. In the supplementary materials, we provide a description of the procedure used to clean the genomic data and calculate the polygenic scores, the code used to link all the data sources together and analyze the data.

Statistical approach

Our analysis consists of four steps. For each of these steps, we estimate a set of linear regression models on our outcomes. This is the standard approach, and seems reasonable given the distribution of our outcome measures. We have eight outcomes, and use 7 different model specifications. We estimate models for both

sexes together, boys only, and for girls only. In total, we estimated 168 regression models in order to obtain the results for this main analysis. In all these models, we include the set of common control variables. As the amount of numeric material is too large to efficiently display in tables, we present all our results here in the form of graphs. Complete tables are available in the supplementary materials.

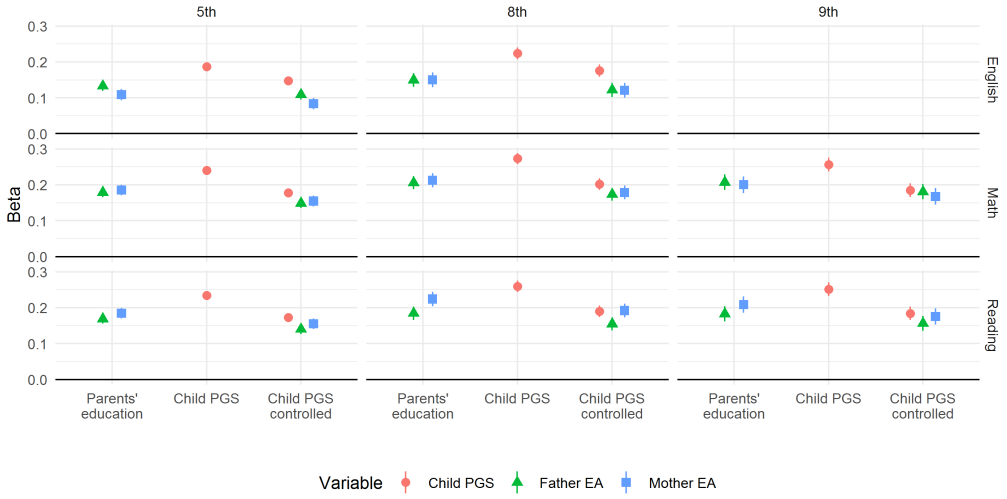
RESULTS

In the first step, we consider the role of child polygenic score as a confounder of the relationship between parents' education and the child's test scores. In the second, we ask to what extent children's test scores are affected by so-called "genetic nurture" effects, i.e. effects of parents' genotypes, above and beyond the child's genetic inheritance of DNA from parents to children. Third, we consider the role of gene-environment interactions, as suggested by the literature inspired by the Scarr-Rowe hypothesis. The fourth step is to consider interactions between parents' genotype and children's genotype, in effect synergies of parent-child similarity in genetically anchored traits.

What is the role of genetic confounding in the association between parents' education and children's test scores?

We want to establish the magnitude of genetic confounding in the association between parents' education and children's test scores. To this end, we first estimate a zero-order model of the association between parents' education and child test scores (denoted "Parents' EA"), a model of the effect of child PGS alone on test scores (denoted "Child PGS"), and then a third model (denoted "Child PGS controlled"), where both parents' education and child polygenic score are included. By comparing results across these models, we can assess the importance of genetic confounding. Figure 1 has eight panels, one for each of the eight standardized tests outcomes. In each panel we plot regression coefficients and their 95% confidence intervals from the three models: On the left the zero-order correlation with parents' education on the left, in the middle the coefficient for the child's polygenic score, and on the right coefficients from the third, combined model.

Figure 1. Genetic confounding of parents' education effects



The model labelled "Parents' education" shows the coefficients for parents' education in a simple model of test scores where no other variables are included (i.e. a zero-order correlation). It shows, in correspondence with the extant literature, that parents' educations have strong associations with child test scores. The results are quite similar across grades and subjects, and the importance of mothers and fathers also seem to be similar in magnitude. Separate figures for analyses done separately for girls and boys are available in the supplementary materials, but we note that there are no major substantively important differences between boys and girls in the effects of own PGS and parents' education on their test performance.

Second, it is clear that the PGS has a strong association with test scores. The estimated coefficient for the child's own PGS is on average 0.18, which means that a one std.dev. increase in the PGS results in 0.24 std.dev. increase in the test score – and the range across subjects/grades is .14–.28. Considered independently, the child's polygenic score is the strongest individual predictor of test performance. But as there are two parents, the total parents' education effect is larger than the effect of the child's polygenic score.

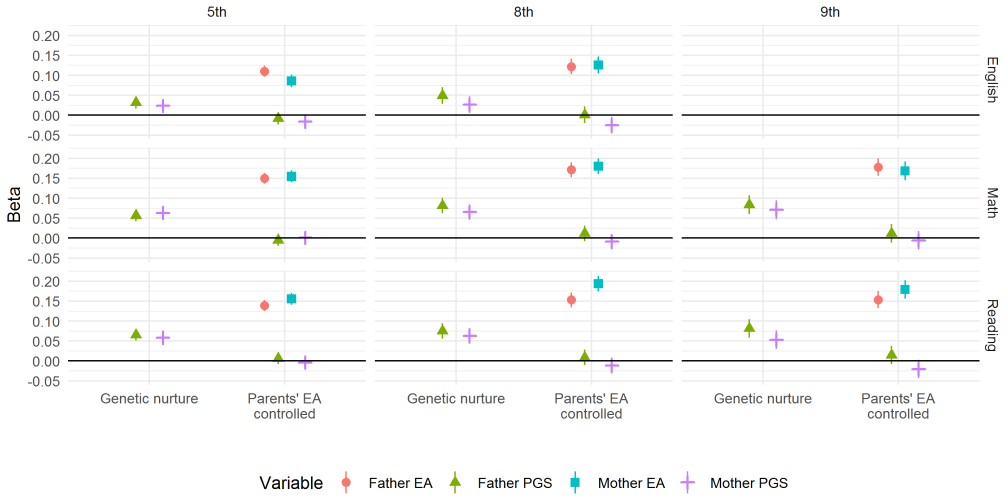
As can be seen from the plot, there are relatively minor changes in the coefficients for parents' education once the child polygenic score for education is controlled. A fairly small fraction of the zero-order effect of parents' education on test scores is confounded by child genetics. The magnitude of the confoun-

ding is similar to what has been reported previously (see e.g. Liu 2018; Conley et al. 2015). Most of the association with parents' education remain after taking the genetic similarities between parents and the child into account.

Are there genetic nurture effects on test scores, and do they persist after controlling for parents' education?

Our second step is to probe the existence of so-called "genetic nurture" effects (Kong et al. 2018). These are effects of parents genotypes above and beyond the direct transmission of DNA from parents to children at conception. In this step, we first model both child's own polygenic score and parents' polygenic scores (model "Genetic nurture"), to assess the magnitude of any genetic nurture effects on test scores. Subsequently, in the "Parents EA controlled" model, we add parents' education measures to assess whether the genetic nurture effects are mediated by parents' educational attainment and whether associations between parents' educations and test scores remain once the genetic profile of child, mother and father all are adjusted for.

Figure 2. Genetic nurture effects with and without controls for parents' education



We do find "genetic nurture" effects on children's educational achievement. The coefficients for the mother's and father's polygenic scores are statistically sig-

nificant and of a measurable, but not large, magnitude. All coefficients are estimated at below a tenth of a standard deviations, and these associations are thus markedly smaller than the coefficient for child's polygenic score. A one standard deviation increase in the a parent's polygenic score is associated with approximately a .06 standard deviation increase in test performance. Again, this pattern is similar across test subjects and grades. Taken at face value, these associations would mean that parents' with high polygenic scores for education shape their children's rearing environments in ways that in turn contribute to their children's improved learning and ultimately higher test score results.

In the next model, labelled "Parents EA controlled", we add parents' actually realized education to the equation. Parents' education is of course a mediator in the causal path from parents' genetics to children's achievement, and thus in principle breaks the causal interpretation of the estimates of parents' PGS. The "genetic nurture" associations between parents' polygenic scores and child test scores are washed out once parents' educations are included. Strong associations between parents' education and test scores remain, when polygenic scores for all three family members are included.

Kong et al. (2018) found that mothers' genetic nurture were more important than fathers' genetic nurture. We examined the importance of mothers relative to fathers, for boys and girls respectively, and found no robust tendency for a baseline difference in nurturing effects between mothers and fathers nor any systematic change over grades. The results are available in the supplementary materials (figure S2).

Interactions: Does the effect of child genotype depend on parental education or genotype?

Our third step is to estimate the strength of any interactions between child genotype and parents' education. The expectation formed by the generalized Scarr-Rowe hypothesis is that effects of a child's genetic dispositions should be stronger in education-rich environments. To test the hypothesis, we interact parental actual (phenotypic) educational attainment with the child's polygenic score. These interaction effects between parents' educational attainments and child PGS would be positive under the generalized Scarr-Rowe hypothesis.

Figure 3. Interaction effects between child genotype and parents' education

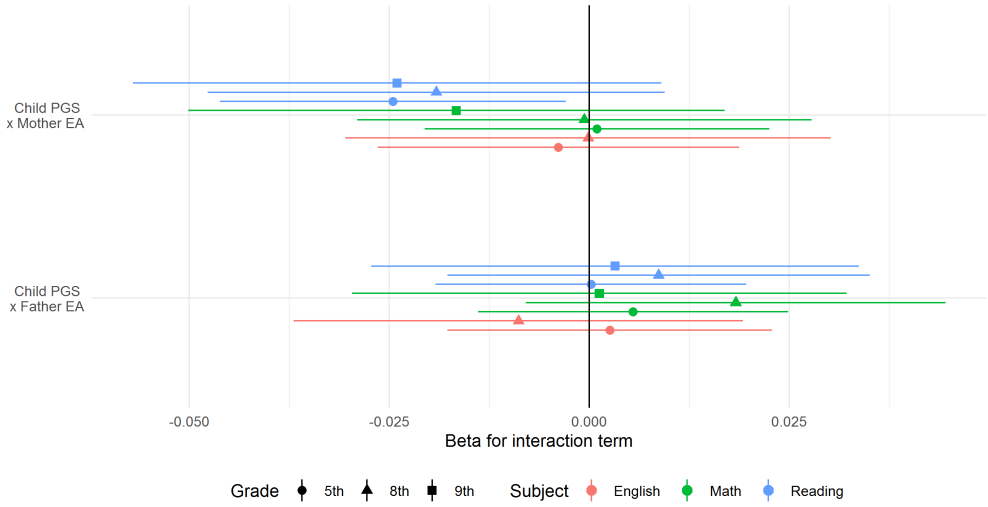
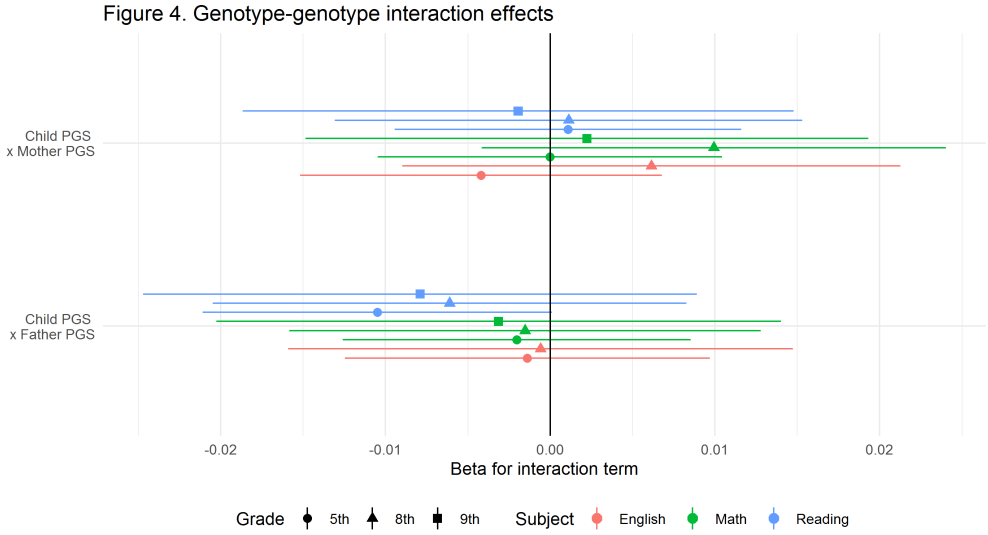


Figure 3 show the interaction coefficients (shown for models for both genders below), which are all hovering around zero with large confidence intervals. Only one of the interaction terms are measurably different from zero, nor are the coefficients of a magnitude that would entail meaningful support for the hypothesis. Moreover, the coefficient is negative, the opposite of what is predicted by the Scarr-Rowe hypothesis. Thus, interactions predicted by the Scarr-Rowe hypothesis between parents' educational attainment and the child's polygenic score are unimportant for children's test scores. The differences between main effects models and the interaction model are also negligible (cf. supplementary materials).

Our fourth and final step is to test for interactions between parents' genetics and their child's genetics. Such interactions have been alluded to earlier (cf. Conley et al. (2015)). If such interactions are found, this is evidence of synergy effects between the genetically shaped traits and interests of parents and children. For example, learning-oriented children would under this hypothesis learn more if they also have learning-oriented parents, above and beyond their already similar genetics.

Figure 4. Genotype-genotype interaction effects



We estimated models interacting the child PGS with the parents' PGSs. Results for these interaction terms are non-significant with confidence intervals overlapping zero, as can be seen from Figure 4. There is no robust evidence of cross-generation genotype-genotype interaction effects. Our results suggest that being a child with education-friendly genetics of a parent with similar dispositions may not create any additional effect on the child's test scores.

DISCUSSION

Our analysis set out to answer four research questions on parents' education, genetics and child educational achievement:

1. What is the role of genetic confounding in the association between parents' education and children's test scores?
2. Are there genetic nurture effects on test scores, and do they persist after controlling for parents' education?
3. Does the effect of child genotype depend on parental education?
4. Are there meaningful child-parent genotype synergies for children's test scores?

Here, we discuss our finding and their implications one by one. First, the role of genetic confounding in the association between parents' education and child-

ren's test scores is small, as only a fraction of the zero-order correlation could be explained by the child's polygenic score for educational attainment. There are "genetic nurture" effects on test scores, effects of parents' genetics above and beyond the child's own genetics. These effects are in turn in their entirety channeled through parents' actually attained educations.

How can we understand these results? If one pits the behavior genetic paradigm (cf. e.g. Polderman et al. 2015; Turkheimer 2000) against the social stratification literature (cf. e.g. Breen and Jonsson 2005), our analysis suggests a draw. The genetic perspective is well supported, as the child's PGS is consistently the strongest single predictor of test scores. The social background perspective, and the idea of parents' (consciously or not) nurturing children to perform well in school, is also supported by the limited role of genetic confounding and the large remaining effect of parents' education. In fact, as there are two parents, the two coefficients for mother's and father's education is in combination larger than the coefficients for the child polygenic score. Comparing our results to sociogenomic literature using twins to investigate the influence from genes and environments, our results fit reasonably well. For education-related outcomes, family environments and additive genetics explain approximate equal parts of the variance (Branigan et al. 2013; Silventoinen et al. 2020).

The associations between parents' educational attainment and children's test scores that remain once all three polygenic scores are controlled, can be interpreted as a result of socioeconomic or sociocultural factors that are socially inherited. This is not to say that parents' genetic dispositions do not matter for test scores. To unlock the advantages of having parents with relatively high polygenic scores for education, the parents' should also have completed such educations. As such, our findings indicate that parental educational attainment have intergenerational effects on children's outcomes. The major remaining caveat to this conclusion lies with the relatively low explanatory power of polygenic scores, as the scores are based on common genetic variants and still pick up only parts of the genetic variation.

Much of the existing literature connecting genetics to educational outcomes is based on data from the United States or other anglophone industrialized countries. Our data comes from Norway, a small Northern European country characterized by a social democratic political economy (Esping-Andersen 1999), relatively marginal differences in school and neighborhood quality (Hermansen et al. 2020) and a strong support system for families. All in all, these macrosocial differences could lead to a stronger genetic confounding of the parent-child correlation and weaker parental education effects on outcomes. That is not what we find. Our re-

sults instead provide evidence for rather important effects of parents' education on children's test scores, and little confounding by children's genotype. In fact, our results correspond well with those reported in the studies that have examined this question previously on educational attainment in the United States (Conley et al. 2015; Liu 2018).

We also found that the effects of child genotype on test scores do not depend on parents' educational achievement, providing no support for the Scarr-Rowe hypothesis in these data. This stands in contrast to some, but not all, of the previous research from the United States (Turkheimer et al. 2003). Norway represents a context where we would expect weak or no such interactions, as both the level of socioeconomic inequalities and institutional differences between these countries point to a less precarious existence for disadvantaged families in Norway.

In sum, our results outlines a world that is simple, linear and independent: Parents' own education affect children's educational performance. Although the effect of the child's own genetically anchored dispositions is the strongest individual predictor, parents' education effects are stronger when we consider the combined effects of the mother and the father. Our findings thus support the idea that even in a universal welfare state with relatively low levels of inequality there are two systems of ascription, one genetic and one social, and these are largely unrelated. The welfare state may be a hindrance to processes where social advantage and genetic advantage overlaps, and thus help keep the two systems of ascription separate.

The findings in the study may lead some to infer that scholars engaged in social stratification do not need to engage with genetics, as genetic and social ascription seems to be fairly independent of each other. However, the child's polygenic score is the strongest individual predictor of test scores, and any analysis leaving out genetics misses a large part of the picture. This alone should spark interest in genetics from scholars of individuals' educational careers and social mobility. The mechanisms linking the child's genetic dispositions towards education to higher actual achievement may well allow a role for parents, for example if they adapt their parenting to their children's talents and orientations. Similarly, other siblings may also be involved if high-PGS children for example act as informal teachers for their siblings. Of such mechanisms, we still know every little.

Our study concerns a specific life course stage: early adolescence. The interplay of genetics and social background may well change over the life course, as children increasing operate independently of their parents and eventually reach adulthood. In early adolescence there is a lot of direct monitoring by parents, and parents may try to assist their children with schoolwork and this may spill over

into the standardized test results. Once children age they will have to rely to a larger degree on their own talents, and there will be less room for parents' active assistance. It It is conceivable that the social background effects we observe may "wear off" at higher ages. Future research should look into these issues by taking advantage of the current abundance of genomic data sources.

Limitations of the study

Our study has multiple strengths, such as the large genotype trio sample and high quality outcome measures, but it also have some limitations. Our main data source, MoBa, has a response rate of 41%, and there is selection into the sample on socioeconomic variables such as education (Magnus et al. 2006). Earlier investigations have found self-selection and underlined the possibility of resulting bias (Biele et al. 2019), and we can see some evidence of it in our own data. Table 1 shows sample means, and the means of the outcome variables are somewhat higher than zero. As these outcome variable are z-standardized over the complete population of test takers, this indicates that the children who participate in MoBa are performing better than the average child on the national standardized tests. When interpreting our results, one should keep in mind that the external validity may be limited to families that are above average in socioeconomic resources. This is a particular challenge to our findings of no Scarr-Rowe interactions. The original Scarr-Rowe hypothesis concerned the effects of deep poverty and deprivation on children's cognition. Our results may not support a strong judgment on the original version of the hypothesis, but can at least offer a conservative test of the extended Scarr-Rowe hypothesis and its relevance in functioning families.

We use polygenic scores, and even though their explanatory power have increased over the last fews and likely will continue to do so, it is still markedly lower than what can be expected from pedigree-based models. The accuracy of a polygenic score depends on the heritability of the trait, the size of the GWAS discovery sample, the degree to which the trait is polygenic and whether the genetic architecture of the trait varies across different environments. Education is a highly polygenic trait. The EA3 GWAS was very large with 1.1. million genomes included, but pooled genomes from societies that diverge quite significantly in terms of their educational systems and political economies, which may affect the set of alleles associated with educational attainment. The polygenic scores we use should be consider incomplete control variables, as they only adjust for the common genetic variants associated with educational attainment, and it may well be that genetic confounding increases when the accuracy of the scores increase.

Conclusions

Using one of the world's largest genotyped trio samples in combination with administrative register data on children's standardized test results in multiple subjects and school grades, this study considered the role of genetics in the parents' education–child test score correlation, the role of genetically-anchored social background effects (or "genetic nurture"), the potential of Scarr-Rowe-type child genetics-parents' education interactions as well as child genotype-parents' genotype interactions. The bulk of the results suggests that a child's genetics is the most important predictor of how well he or she does on standardized tests. Parents' education also has a strong association with test scores, even when both the child's and the parents' genetics are accounted for. We identified no important interactions between child education polygenic score on the one hand and parents' education polygenic score actually attained education on the other hand.

The main conclusion of our study is thus, limitations of the study aside, that there are two independent sources of advantage in children's early educational careers. One source is biological in the sense that it is rooted in the child's genetic dispositions, and the other is social and rooted in environmental factors associated with parents' own actual educational attainments. These two systems of ascription seem largely independent of each other. Social inequalities, poverty and variation in school quality is less in Norway than in most other countries. The Scandinavian welfare state provides a relatively level playing field for children from different socioeconomic backgrounds in the educational system and alleviates many negative consequences of low SES for parents. We would expect the association between parents' educations and children's test scores to be smaller in Norway, but the association remains even when accounting for genetic transmission. Both genetic and social background matters for children's educational performance in early adolescence, showing the continued relevance of the "social background paradigm" for intergenerational transmission of educational outcomes.

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