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Does Parental Separation Lower Genetic Influences on Children's School Performance?

Objective: A behavioral genetics approach is used to test whether parental separation lowers the importance of genes for children's school performance.

Background: The Scarr–Rowe hypothesis, which states that the relative importance of genes on cognitive ability is higher for advantaged compared to disadvantaged children, has been expanded to educational outcomes. However, advantage/disadvantage is predominantly conceptualized as parental socioeconomic status and neglects other important factors. This study expands upon the literature to include family structure as an indicator for advantage/disadvantage.

Method: Data from TwinLife, a new population-register-based sample of twins and their families in Germany, and ACE variance

decomposition models are used to estimate the heritability of cognitive ability ($N_{\text{Pairs}} = 896$), school grades ($N_{\text{Pairs}} = 740$), and academic self-concept ($N_{\text{Pairs}} = 949$) separately for single-parent and two-parent households.

Results: Findings show that the relative importance of genes on children's cognitive ability and academic self-concept is lower for children in single-parent households compared to two-parent households (32–47% and 23–50%, respectively), but differences are negligible for math grades (41–43%). ACE models adjusted for mothers' education and household income retrieve substantively similar results.

Conclusion: The quality of the family environment that is important for the realization of children's genetic potential is not just shaped by socioeconomic status, but also family structure.

INTRODUCTION

A prominent theme in sociology revolves around the extent that family background affects children's educational attainment. One important question is how differences in the resources available to families across social strata affect child development, especially those that are important predictors for children's educational outcomes. However, various indicators of school performance are not only shaped by parents' resources but also by children's genes (e.g., Eifler et al., 2019; Gottschling et al., 2012; Johnson et al., 2006; Kovas et al., 2015; Krapohl et al., 2014; Pokropek & Sikora, 2015).

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Key Words: education, gene–environment interaction, parental separation, school performance, twins.

Importantly, the relative importance of genetic influences could be dependent on environmental conditions that children encounter. The family context is particularly important given that children's development takes place under environmental conditions provided by parents.

Research on IQ and educational outcomes has acknowledged the role of the family and considers parents social standing (e.g., Baier & Lang, 2019; Gottschling et al., 2019; Guo & Stearns, 2002; Turkheimer et al., 2003). This research is inspired by the Scarr–Rowe hypothesis, which states that genes relevant for cognitive ability are more important among advantaged children compared to disadvantaged children (Rowe et al., 1999; Scarr-Salapatek, 1971). It is argued that advantaged parents provide a rearing environment that enhances genetic influences, while environmental conditions provided by socioeconomically disadvantaged parents tend to suppress the realization of genetic potential.

A major short coming of the previous literature is that children's advantage and disadvantage has almost exclusively been measured in terms of parental socioeconomic status, such as parental education, income, occupation, or summative indices (e.g., Baier & Lang, 2019; Conley et al., 2015; Guo & Stearns, 2002; Turkheimer et al., 2003). However, parental socioeconomic status alone may not adequately capture a key dimension of advantage and disadvantage during childhood (e.g., Esping-Andersen, 2007; McCall & Percheski, 2010; Western et al., 2016). For example, McLanahan (2004) argued in her seminal article that the growth in single-mother households is a major component of the growing disparities among children in the United States. In this study, we concentrate on one dimension of family structure, namely whether children live with both biological parents or in a single-parent household generated by parental separation.

Parental separation is thought to be associated with less advantageous outcomes for children not only on account of socioeconomic differences between two- and single-parent households, but also due to factors associated with family instability (Cavanagh & Fomby, 2019). Specifically, parental separation may change parenting behaviors, decrease parents' ability to monitor their children's activities, and increase stress among children (e.g., Cooper et al., 2011; Hadfield et al., 2018;

Lee & McLanahan, 2015). We argue that parental separation and its associated family processes create a distinct set of environmental conditions that can suppress the importance of genes for children's school performance.

Against this background, we address the following two research questions: *First, does parental separation lower the heritability of children's school performance?* Heritability is a well-known statistic, which expresses the proportion of individual differences that can be explained with genetic as opposed to environmental variation. Put simply, heritability estimations tell us to what extent genes matter in relation to social influences. We assess the heritability of three indicators of school performance for children in two-parent households compared with children in one-parent households who experienced a parental separation. *Second, are the differences in the heritability of children's school performance attributable to differences in parental education and income?* This gives us leverage on whether differences in the relative importance of genes between single- and two-parent households are attributable solely to socioeconomic differences or whether other mechanisms related to family instability create family environments that lower children's chances for the realization of genetic potential. It is important to know whether the importance of genes for children's school performance varies by family structure for at least two reasons. First, it has implications for our understanding of how inequalities are reproduced among children in single-parent families (McLanahan & Percheski, 2008). Second, it has implications for the effectiveness of social policies that are targeted toward children who experienced a parental separation and are growing up in single-parent households.

We use novel data from the German TwinLife panel study (Diewald et al., 2017). TwinLife is a population-register based sample of monozygotic and same-sex dizygotic twins and their families residing in Germany. To study whether parental separation moderates the impact of genetic influences relevant for children's school performance, we estimate genetically sensitive variance decomposition models, so called ACE models (e.g., Plomin et al., 2008). These models enable us to decompose the variance of our school performance indicators into an additive genetic component (A), a common or shared environment component (C), and an

environment component that is unique to each twin (E). In our study, we are interested in whether the additive genetic component, that is the heritability, varies systematically by family structure.

We make both theoretical and empirical contributions to the literature. First, we introduce a conceptual model of how parental separation moderates the heritability of children's school performance through enhancement and suppression mechanisms (Shanahan & Hofer, 2005). Specifically, we argue that parental separation exposes children to stressful environments, which leads to a suppression of genetic influences related to school performance. Second, we are the first to provide evidence that the importance of genes for certain indicators of school performance is lower for children living in single-parent households following a separation compared to those living in households with two biological parents. Moreover, we demonstrate that those differences are not solely accounted for by socioeconomic differences between two- and single-parent households.

THEORETICAL BACKGROUND

Indicators of Children's School Performance

How well children fare in school is pivotal for their later life chances, because school performance is directly linked educational attainment and mobility. We consider children's school performance an umbrella term for children's academic achievement, cognitive ability, and academic motivation. While these three dimensions of children's school performance are closely intertwined, they are related to each other and contribute to school performance in distinct ways. Academic achievement, often measured using grades or test scores, is assessed by teachers and reflects children's performance in schools. One important input factor for academic achievement is children's cognitive ability (e.g., Strenze, 2007). Although the relationship is bidirectional, academic motivation is a major indicator for noncognitive skills and associated with educational achievement (see e.g., Gutman & Schoon, 2013). Self-perceived ability, that is, children's subjective reflections about previous performances, represents an important precursor for children's achievement motivation (Denissen et al., 2007; O'Mara et al., 2006).

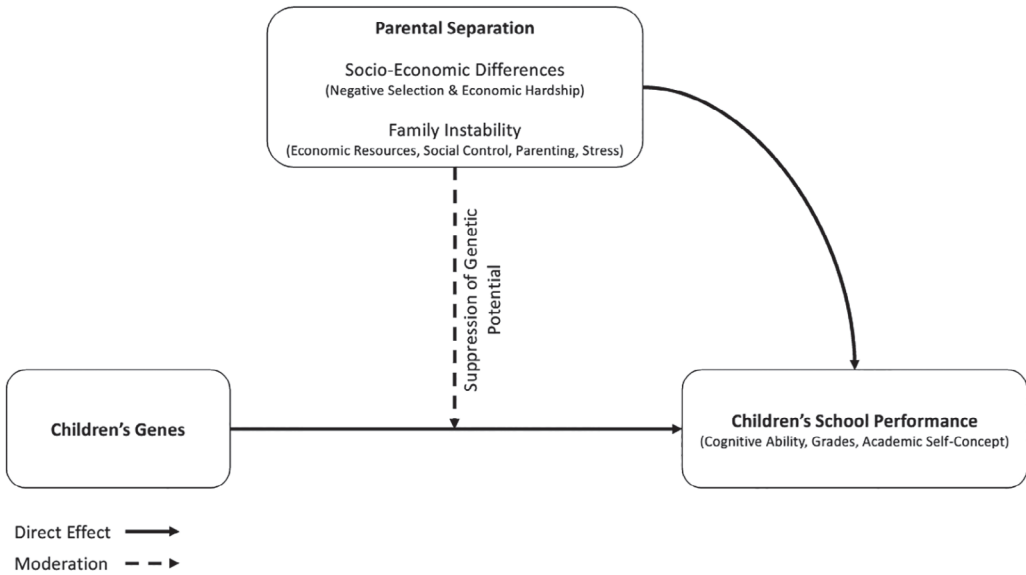
To elaborate how parental separation affects children's school performance, we bridge established theories rooted in family demography and sociology with behavioral genetic approaches (see Figure 1). We first refer to the literature that links parental separation and children's school performance. We then review the evidence that genetic influences also need to be considered to understand differences in children's school performance. Finally, we combine both strands of literature and elaborate how differences in the quality of the family environment by family structure may moderate the impact of genetic influences on school performance.

Parental Separation and Children's School Performance

One of the most dramatic changes to children's families and home environments since the 1960s has been the increase in parental separation (Cherlin, 2010), which has been shown to be negatively associated with children's school performance (see Amato & Keith, 1991; Amato, 2001 for meta-analyses; see Amato, 2000, 2010; Raley & Sweeney, 2020 for reviews). Numerous studies have found a negative relationship between parental separation and children's educational attainment, often measured in terms of grades or attained levels of education, although effects have been shown to vary across social groups (e.g., Bernardi & Boertien, 2016; Brand, Moore, Song, & Xie, 2019; Brand, Moore, Song, & Yu, 2019; Grätz, 2015). Parental separation has also been shown to have a persistent negative impact on children's cognitive skills (Carlson & Corcoran, 2001; Cooper et al., 2011; Fomby & Cherlin, 2007; Kim, 2011). Although fewer studies have assessed the association between parental separation and children academic motivation and self-perceived academic ability, research demonstrates that children in divorced households have lower academic self-concepts than children in biological two-parent households (e.g., Sweeney & Bracken, 2000).

Two sets of theoretical approaches have been put forward in the literature to account for the negative relationship between parental separation and outcomes for adults and children: selection and causation (Amato, 2000, 2010). The former posits that the association between parental separation and children's outcomes results from parents' negative selection

FIGURE 1. PARENTAL SEPARATION AS MODERATOR FOR GENETIC INFLUENCES ON CHILDREN'S SCHOOL PERFORMANCE.



into divorce. In other words, children's school performance is lower in less educated households with lower incomes, which are also more likely to divorce. Studies that include pre-separation characteristics, such as parents' educational attainment and income, have found that the associations between parental separation and children's school performance attenuates considerably (e.g., Aughinbaugh et al., 2005; Fomby & Cherlin, 2007).

Post-separation socioeconomic differences have also been associated with negative outcomes for children. Parental separation leads to greater economic hardship and increased financial volatility, which has been shown to negatively affect children's school performance and cognition (e.g., Bernardi & Boertien, 2016; Carlson & Corcoran, 2001; Nonoyama-Tarumi, 2017; Thomson et al., 1994). Socioeconomically advantaged parents tailor children's home and learning environments to actively foster children's skills formation processes and provide additional learning materials and/or private tutoring to improve their children's chances for educational success. In addition, advantaged parents transmit cultural interests and resources, which are positively associated with children's school-related skills (e.g., Cunha & Heckman, 2008; Lareau, 2011; Lareau & Weininger, 2003).

However, many scholars argue that parental separation has a causal negative effect on children's school performance above and beyond socioeconomic differences between two- and single-parent households. One of the most prominent theoretical approaches, the family instability perspective, draws on both static and dynamic theories on the adverse consequences of parental separation (see Cavanagh & Fomby, 2019 for a review). Parental separation may change parents' behaviors and parenting strategies as well as children's perceptions of parenting practices (Sirvanli-Ozen, 2005). Researchers from developmental psychology and educational science, often underscore the link between parent's childrearing behaviors, orientations, and strategies with children's academic development and performance (see Porumbu & Necşoi, 2013; Taylor & Rowley, 2004). For example, authoritative parenting associated with high levels of parental warmth, responsiveness, and demandingness coupled with low levels of negativity and conflict is associated with better school-related outcomes (Spera, 2005). In contrast, more distant parenting characterized by higher levels of negative emotions among parents, for example, stress and depression, may undermine children's academic socialization.

Moreover, it may be more difficult for a single parent compared to two parents to monitor and control their children's activities due to increased time constraints and reduced social networks. In addition, children in households characterized by lower levels of closeness may be less likely to share information about their whereabouts and activities with their parents. Parents' knowledge about their children's activities is an important predictor of a wide range of outcomes, from delinquency to educational attainment (Kerr et al., 2010; Stattin & Kerr, 2000) and has been shown to partially mediate the negative outcomes of parental separation (e.g., Fröjd et al., 2007). In sum, the negative effects of parental separation on children's school performance may be attributable to more than just negative selection into in parental separation and fewer economic resources, but are also due to change in family stability, parenting behavior, social monitoring, and stress levels (e.g., Cooper et al., 2011; Hadfield et al., 2018; Lee & McLanahan, 2015).

Genetic Influences on Children's School Performance

What has often been neglected in theoretical approaches surrounding the adverse consequences of parental separation is that not only material and nonmaterial resources contribute to differences in school performance but also genetic influences (e.g., Eifler et al., 2019; Gottschling et al., 2012; Johnson et al., 2006; Kovas et al., 2015; Krapohl et al., 2014; Pokropek & Sikora, 2015). The various pathways that link single genetic variants with complex traits, such as school performance, are not yet fully understood. However, it is widely acknowledged that a large number of genetic variants are involved and that the impact of genetic influences operate through intermediate psychological and/or physiological characteristics (Freese, 2008). Discounting the role of genes may therefore lead to incomplete and possibly wrong conclusions about how differences in school performance emerge.

Genetic influences for indicators of school performance are well established. For cognitive ability, which has a long research tradition in behavioral genetic research, genes account for about 40% of the total variation in childhood and up to 80% in adulthood (e.g., Haworth et al., 2010). For educational achievement,

genetic influences are also quite substantial (see Pokropek & Sikora, 2015 for an overview). Heritability estimations for school grades range from about 34% to 70% (Eifler et al., 2019; Johnson et al., 2006; Pokropek & Sikora, 2015). Findings for academic motivation, indicated by enjoyment or self-perceived ability, are more homogenous with heritability estimations of roughly 40% (Gottschling et al., 2012; Kovas et al., 2015). The heritability estimations for different indicators of school performance provide insights about the role of genes and whether children can express their genetic potential related to education. However, when considering genetic influences relevant for education and its predictors, it is important to take into account that the relative importance of genes can depend on environmental conditions (e.g., Heath et al., 1985; Herd et al., 2019; Guo & Stearns, 2002; Turkheimer et al., 2003; Gottschling et al., 2019; Baier & Lang, 2019).

Gene–Environment Interaction and Parental Separation

Our conceptual framework combines these two strands of literature. Perspectives on the association between parental separation and children's school performance focus on socioeconomic differences between single- and two-parent families as well as on changes in social control, parenting, and children's stress levels. However, parents transmit not only social resources and experiences but also their genes that both affect children's school performance directly. The main contribution of our conceptual framework is that we consider parental separation and its associated family processes as a distinct set of environmental conditions that can moderate the importance of children's genes relevant for school performance.

Shanahan and Hofer (2005) differentiated between four ideal-typical processes to describe how environmental exposures affect genetic influences: triggering, compensation, social control, and enhancement. These processes are not mutually exclusive and can act together. Triggering describes situations in which genetic influences are expressed only under specific environmental influences. In the case of compensation, environmental influences work in the opposite direction in the sense that they prevent the realization of genes. Social control refers to situations in which individuals' genetic

dispositions are lowered due to social norms or values that restrict behaviors or actions. All of these processes predominantly refer to genetic risks or vulnerabilities. Enhancement mechanisms by contrast describe how stable exchange with enriched social settings increase genetic influences on favorable outcomes by pushing developmental functioning to a higher level. The enhancement mechanism is well suited to explain how changes in the family environment driven by a parental separation affect the relative importance of genetic influences on school performance.

Enhancement has often been used to explain the Scarr–Rowe interaction, which describes an increase in genetic effects on IQ by parents' socioeconomic status. The starting point is the bioecological model, which states that individual development takes place in constant exchange with the environment through the so-called proximal processes set by the immediate family context (Bronfenbrenner & Ceci, 1994). Previous research on the Scarr–Rowe hypothesis has focused on parents' socioeconomic standing (e.g., Baier & Lang, 2019; Guo & Stearns, 2002; Turkheimer et al., 2003) and more recently school-level socioeconomic status (Trejo et al., 2018). The underlying assumption is that socioeconomically advantaged parents provide enriched rearing environments and stable exchange with proximal processes, which leads to stronger genetic influences on IQ compared to impoverished social settings that tend to suppress genetic influences on IQ.

We argue that this expectation also holds for family structure, because parental separation marks a period of instability characterized by a loss in emotional and economic resources. Due to periods of economic hardship, separated parents may not be able to provide relevant goods or services that further the development of children's cognitive and noncognitive skills. In addition, separated parents may spend less time with their children and are less able to respond to children's needs or to monitor children's homework and/or to organize their enrichment activities. Discontinuities of both types of resources are important, because they can hinder or even block enhancement mechanisms as they unfold under stable exchange with beneficial environments. As a consequence, children lack tailored inputs that are adapted to their needs and in line with their genetic dispositions.

Moreover, parental separation increases children's exposure to stressful environments, which can lower children's chances for the realization of their genetic potential. Parental separation leads to higher levels of psychological distress due to family conflicts, economic hardship, or a combination of both. Spill-over effects of stress from parents to children might be intensified since separated parents apply parenting behavior that can buffer or protect children from stressful environments, characterized by emotional warmth, responsiveness, and sensitivity, less often (Sandler et al., 2008). Extended periods of the exposure to stressful environments negatively affect cognitive functioning (e.g., Lupien et al., 2009), which can lead to a suppression of genetic influences (see also Lang et al., 2020).

Taken together, the lack of enhancement due to discontinuities in the provision of (non-)material resources and increased exposure to stress can lead to a suppression of genetic influences for children who experience a parental separation. Against this background, we expect that *genetic influences on children's school performance will be higher in two-parent households compared to single-parent households generated by parental separation (H1)*. However, if the differential rearing environments created by two-parent and single-parent families following separation are due solely to socioeconomic differences, for example, negative selection and economic hardship, then the heritability of school performance would not be higher in two-parent households compared to single-parent households once adjusted for socioeconomic status. However, if family instability processes following parental separation, such as a change in social control, parenting, and stress, suppress genetic influences on children's school performance, then *genetic influences on children's school performance will be higher in two-parent households compared to single-parent households generated by parental separation even when adjusted for parental education and household income (H2)*.

To date, few studies have examined whether the exposure to parental separation moderates the impact of genetic influences and have focused on delinquency or problem behavior. Findings based on molecular approaches using candidate genes suggest that individuals equipped with specific variants of dopamine receptors were more likely to report

externalizing behaviors in divorced families compared to intact families (Nederhof et al., 2012), while findings with regard to specific receptors differ across studies (Guo et al., 2008; Waldman, 2007). While the idea of testing whether predefined genetic variants that are associated with the outcome of interest vary by environmental conditions is appealing, candidate genes studies have been criticized due to low replicability (e.g., Dalton & Fletcher, 2017; Duncan & Keller, 2011). Studies using quantitative approaches based on twins showed that genetic influences on internalizing and externalizing problems are weaker in divorced families compared to intact families (Hicks et al., 2009; Robbers et al., 2012), while the lower heritability was due to greater environmental influences in divorced families. To our knowledge, our study is the first to present a conceptual model of how parental separation may moderate the importance of genes on children's school performance and test this empirically.

DATA AND METHODS

Sample

We used the first wave of the newly collected data from the TwinLife study (Diewald et al., 2017). TwinLife started in 2014 and provides a population-register based sample of monozygotic (MZ) twins, same-sex dizygotic (DZ) twins, and their families residing in Germany. TwinLife applies a social and regional stratified probability-based sampling strategy, which enables us to analyze twin families from a broad range of the social spectrum (Lang & Kottwitz, 2020). Our target population refers to twin pairs from the second birth cohort (2003/2004), aged 10–12.

Outcome Variables

We selected three different indicators for school performance: cognitive ability as the most important single input factor for education, math grades as an indicator for educational performance, and math academic self-concept as motivational measure. We measured children's cognitive ability with the Culture Fair Intelligence Test (CFT 20-R). The CFT is a widely used standard psychometric test to indicate nonverbal (fluid) intelligence (Weiß, 2006). The test consists of four subtests (figural reasoning, figural classification, matrices, and combined

reasoning (see Gottschling, 2017 for implementation in TwinLife)). Children's cognitive ability scores are based on the sum scores for each of the subtests and were age-corrected (Weiß, 2006). Missingness was moderate (3.6%).

Math grades were retrieved from pictures of children's most recent report card (Mattheus et al., 2017). If the most recent certificate was not available, then grades were assessed via parental reports. Grades ranged from 1 (*excellent*) to 6 (*insufficient*). As Germany has a highly stratified schooling system, we controlled for the school types that children attended to account for school-type differences. The results did not substantially change when running the analyses without controlling for school type. In addition, we excluded children that attended a Waldorfschule, which have a different grading system, as well as children attending special needs schools (less than 2%). Missingness for grades was roughly 15%.

Finally, we operationalized self-perceived ability using the following three items on math academic self-concept, which were measured on a five-point scale (see Dickhäuser et al., 2002): (1) I am...in math (1 *not talented* to 5 *talented*); (2) I know...in math (1 *just a little* to 5 *a lot*); (3) In math, many things are... (1 *easy* to 5 *difficult*). We created children's scores for math academic self-concept using confirmatory factor analysis based on a structural equation model. We deleted cases in which information on all three items were missing (less than 1%). We used the inverse hyperbolic sine to transform the left-skewed distribution of math academic self-concept to account for a non-normal distribution. We deleted cases with missing information on the dependent variables and created one sample for each outcome.

Independent Variables

To test whether household composition affects the relative importance of genetic influences on our indicators of school performance, we distinguish between children who live in two- and single-parent households. Children living with both biological parents, married or cohabiting, are categorized as living in two-parent households. Unfortunately, cohabitation and marriage cannot be differentiated in the TwinLife data. Children in single-parent households are living with a mother who is either single (27%), separated or divorced (60%), or married,

living permanently apart (13%). We excluded step-families (4%), single fathers, and same-sex couples, as well as widowers (each less than 1%). In addition, we removed single-parent families where the father never lived in the twin's household (9%) or for whom these data were missing (3%). Therefore, twins in our sample experienced a parental separation sometime between birth and the survey, that is, between ages 0 and 12.

We used mothers' education and household income to approximate differences in socioeconomic background. We chose both indicators to explore the role of financial resources and also transmission mechanisms that are more directly linked to the development of cognitive ability and academic success, such as stimulating home and learning environments, parenting practices, and educational resources (e.g., Cunha & Heckman, 2008; Duncan et al., 1998; Lareau & Weininger, 2003). Rather than including a large number of binary variables based on school and vocational degrees, we measured mother's education with years of education. We used information on both school and vocational degrees/certificates and transformed this into a measure of years of education using the established coding scheme for Germany (Socio-Economic Panel Group, DIW Berlin, 2017). Additional analyses based on mothers' International Standard Classification of Education level instead of mothers' years of education lead to substantively similar results. We mean-centered mother's education in the adjusted models. Financial resources were quantified as log monthly net household incomes equalized using the Organisation for Economic Co-operation and Development scale. Due to missing information for mother's education (4%) and household income (13%), we used multiple imputation based on chained equations and 20 datasets per observation (Van Buuren et al., 2006). In total, 15.3% ($N_{\text{Pairs}} = 137$) live in single-parent families in the cognitive ability sample, 14.9% ($N_{\text{Pairs}} = 110$) in the math grades sample, and 15.1% ($N_{\text{Pairs}} = 143$) in the self-perceived ability sample. Although our sample of twins living in single-parent households is relatively small, it is large enough for us to demonstrate systematic heritability differences between single- and two-parent households across all three dependent variables.

Summary statistics by zygosity for each sample are displayed in Table 1. Table 1 shows that

sociodemographic characteristics are distributed fairly similarly among MZ and DZ twins. Note that twins' age and also gender do not vary within twin pairs, because our sample includes MZ and same-sex DZ twins. Age and gender are therefore not included in the analyses. We did not control for age since the age range is small (i.e., 10–12) and cognitive ability is already adjusted for age (see above). To capture differences by sex, separate analyses by gender would have been necessary, which is not feasible given the small sample sizes and beyond the scope of the current study. In line with previous research on parental separation (e.g., Brand, Moore, Song, & Xie, 2019; Kim, 2011; Sweeney & Bracken, 2000), mean values are for all three outcomes on average higher in two-parent families compared to one-parent families, and statistically significant for cognitive ability and math grades ($p < 0.01$).

The Classical Twin Design and ACE Decompositions

We assessed the relative importance of genetic influences on children's school performance by family structure using the Classical Twin Design (CTD). The CTD is widely used in behavioral genetics to estimate to what extent differences in phenotypes can be explained with differences in genetic influences and differences in environmental exposures (Plomin et al., 2008). The CTD design identifies the relative importance of additive genetic influences, which is a known heritability estimate.

Twins are born and raised at the same time. MZ twins are additionally genetically alike, while DZ twins share on average about 50% of their DNA. The CTD builds upon these distinct features to decompose the total variance of an outcome into variance that can be attributed to additive genetic influences (A), shared environmental influences (C), and unique environmental influences including the measurement error (E). This method is labeled the ACE variance decomposition method.

To test our hypothesis we proceed in two steps. First, to test our first hypothesis, we estimated ACE models for each outcome using a linear multilevel mixed-effects parameterization separately for twins in one- and two-parent households (e.g., Guo & Wang, 2002; Rabe-Hesketh et al., 2008). The estimation of ACE components by subgroups is also known as

Table 1. Descriptive Statistics

	One parent						Two parents					
	MZ twins			DZ twins			MZ twins			DZ twins		
	Mean	SD	Max	Mean	SD	Max	Mean	SD	Max	Mean	SD	Max
Sample 1: Cognitive ability												
<i>Individual (twin-) level variables</i>												
Cognitiveability	95.31	55.00	148.00	95.47	60.00	148.00	99.28	55.00	148.00	99.71	55.00	148.00
	16.01			15.52			16.34			16.03		
<i>Family (twin-pair-) level variables</i>												
Age	11.02	10.00	12.00	11.00	10.00	12.00	11.01	10.00	12.00	11.00	10.00	12.00
	0.33			0.29			0.38			0.29		
Girl	0.63	0.00	1.00	0.57	0.00	1.00	0.52	0.00	1.00	0.51	0.00	1.00
	0.48			0.50			0.50			0.50		
Mother's education												
Years	12.75	7.00	18.00	13.24	7.00	20.00	13.71	7.00	20.00	14.06	7.00	20.00
	2.88			3.15			3.03			3.03		
Net household equiv. income												
Log	7.12	5.00	8.50	7.15	5.00	8.00	7.29	4.50	9.50	7.37	5.00	10.00
	0.62			0.61			0.72			0.70		
N_{Pairs}	65			72			300			459		
Sample 2: Math grade												
<i>Individual (twin-) level variables</i>												
Math grade	2.69	1.00	5.00	2.72	1.00	5.00	2.53	1.00	5.00	2.43	1.00	6.00
	0.93			0.92			0.89			0.88		
<i>Family (twin-pair-) level variables</i>												
Age	11.04	10.00	12.00	11.03	11.00	12.00	11.00	10.00	12.00	11.01	10.00	12.00
	0.35			0.18			0.38			0.28		
Girl	0.64	0.00	1.00	0.57	0.00	1.00	0.51	0.00	1.00	0.52	0.00	1.00
	0.48			0.50			0.50			0.50		
Mother's education												
Years	12.94	7.00	18.00	13.49	7.00	20.00	13.68	7.00	20.00	14.13	7.00	20.00
	3.17			3.12			3.01			2.94		
Net household equiv. income												
Log.	7.15	5.00	8.50	7.15	5.00	8.00	7.31	5.00	9.50	7.39	5.00	9.50
	0.65			0.62			0.72			0.69		
N_{Pairs}	50			60			258			372		
Sample 3: math academic self-concept												
<i>Individual (twin-) level variables</i>												
Acad. self-concept	-0.08	-1.76	1.06	-0.02	-1.81	1.06	0.01	-1.81	1.06	0.03	-1.81	1.06
	0.82			0.84			0.78			0.75		
<i>Family (twin-pair-) level variables</i>												
Age	11.01	10.00	12.00	11.01	10.00	12.00	11.00	10.00	12.00	11.00	10.00	12.00
	0.32			0.26			0.38			0.29		
Girl	0.60	0.00	1.00	0.59	0.00	1.00	0.53	0.00	1.00	0.50	0.00	1.00
	0.49			0.49			0.50			0.50		
Mother's education												
Years	12.90	7.00	18.00	13.25	7.00	20.00	13.69	7.00	20.00	14.03	7.00	20.00
	2.94			3.11			3.04			3.01		
Net household equiv. income												
Log.	7.15	5.00	8.50	7.15	5.00	8.00	7.28	4.50	9.50	7.37	5.00	10.00
	0.62			0.60			0.71			0.70		
N_{Pairs}	68			75			318			488		

Source: TwinLife wave 1; own calculations.

nonparametric gene–environment interaction analyses (Guo & Wang, 2002). Second, in order to test whether any potential change in heritability is a function of socioeconomic differences between two- and single-parent families, we extended this estimation strategy by controlling for mother’s education and household income, analogous to a linear regression approach. An alternative approach to account for selection effects, or socioeconomic differences more generally, is to first regress the outcome on mothers’ education and household income, respectively, and then decompose the residuals. Both approaches lead to the same results. We chose to control for mothers’ education and household income, respectively, because it allows us estimate the proportion of total variance for each outcome that is accounted for by mothers’ education and household income. All our analyses are estimated in Stata using `acelong.ado` (Lang, 2017).

RESULTS

Figure 2 shows how the relative importance of genetic influences (A), shared environmental

influences (C), and unique environmental influences (E) for cognitive ability, math grades and math academic self-concept for children living with one and two parents (unadjusted), and whether these results change once we adjust for mother’s education and for household income (see also Table 2). Overall findings, not estimated separately for single- and two-parent households, can be found in the online supplement (Table A1). Findings on the absolute variance components are also shown in the online supplement (Figure A2).

We found that genetic influences were larger in two-parent compared to one-parent families for all outcomes, although differences tend to be negligible for math grades. In one-parent families, genetic influences accounted for about a third of the total variation in cognitive ability (32%), and for nearly half of the total variation in two parent families (47%, respectively). Differences are even more striking for math academic self-concept. While less than one-fourth of the total variance in math academic self-concept is attributable to genes in one-parent families, half of the variance is accounted by genes in two-parent families (23%

FIGURE 2. ACE VARIANCE DECOMPOSITIONS FOR TWINS COGNITIVE ABILITY, MATH GRADE, AND MATH ACADEMIC SELF-CONCEPT BY PARENTAL SEPARATION – UNADJUSTED, ADJUSTED FOR MOTHER’S EDUCATION, AND ADJUSTED FOR NET HOUSEHOLD EQUIVALENT INCOME. VARIANCE COMPONENTS IN PERCENT.

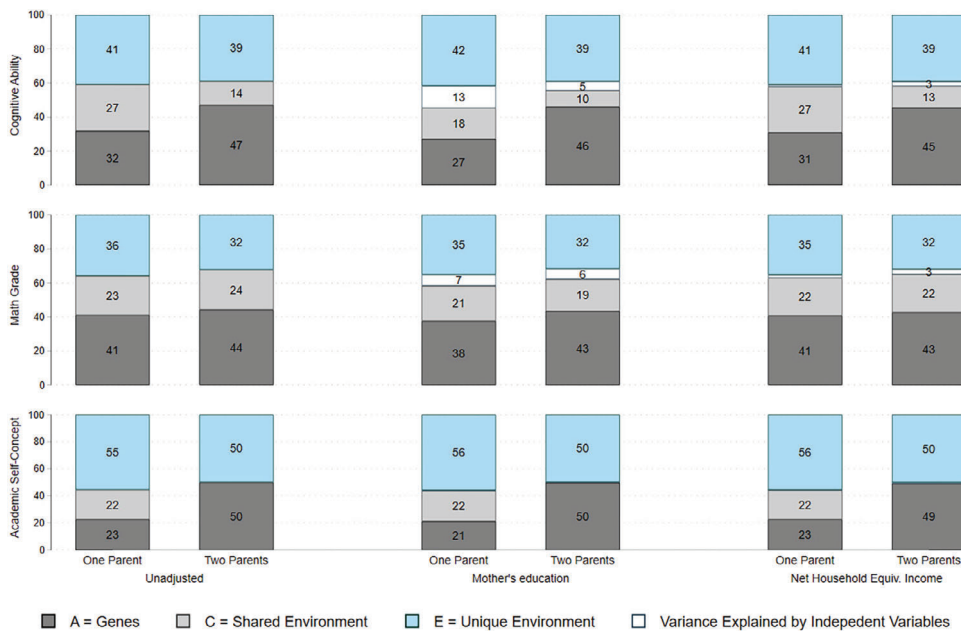


Table 2. ACE Variance Decompositions for Twins Cognitive Ability, Math Grade, and Math Academic Self-Concept by Parental Separation – Unadjusted, Adjusted for Mother’s Education, and Adjusted for Net Household Equivalent Income

	One parent					Two parents				
	b/var	c.s.e	z-value	95% CI		b/var	c.s.e	z-value	95% CI	
Cognitive ability										
Constant	95.4	1.2	81.8***	93.1	97.7	99.6	0.5	198.9***	98.6	100.5
Total var.	246.3	27.7	8.9***	197.6	307.0	260.6	10.6	24.5***	240.5	282.3
A in %	31.8	23.0	1.4	10.1	65.8	47.1	10.0	4.7***	37.0	57.4
C in %	27.3	18.0	1.5	9.3	57.8	14.0	8.4	1.7†	4.7	34.6
E in %	40.8	7.5	5.4***	32.4	49.7	38.8	3.2	12.0***	35.0	42.8
Mother’s education										
Constant	95.4	1.1	89.9***	93.3	97.4	98.4	0.5	194.7***	97.4	99.4
Mother’s educ.	1.9	0.3	5.9***	1.2	2.5	1.2	0.2	7.8***	0.9	1.5
Total var.	246.3	27.7	8.9***	197.6	307.0	260.6	10.6	24.5***	240.5	282.3
A in %	27.1	22.1	1.2	7.0	64.8	46.1	9.9	4.7***	36.0	56.5
C in %	18.2	15.8	1.2	3.9	55.0	9.5	8.2	1.2	1.9	36.1
E in %	41.6	7.9	5.3***	33.0	50.8	39.0	3.3	12.0***	35.2	43.0
R ² in %	13.1					5.4				
Net household equivalent income										
Constant	80.0	16.9	4.7***	46.9	113.1	73.3	6.0	12.3***	61.5	85.0
Net HH equiv. inc.	2.2	2.4	0.9	-2.5	6.8	3.6	0.8	4.4***	2.0	5.2
Total var.	246.3	27.7	8.9***	197.6	307.0	260.6	10.6	24.5***	240.5	282.3
A in %	30.9	22.8	1.4	9.5	65.5	45.4	9.9	4.6***	35.2	56.0
C in %	27.0	17.4	1.6	9.5	56.6	12.8	8.1	1.6	4.1	33.8
E in %	40.9	7.6	5.4***	32.5	49.9	39.1	3.3	12.0***	35.3	43.1
R ² in %	1.2					2.6				
N _{Pairs}	137					759				
Math grade										
Constant	2.8	0.2	15.6***	2.4	3.1	2.4	0.1	49.9***	2.3	2.5
Total var.	0.8	0.1	10.4***	0.7	1.0	0.8	0.0	22.0***	0.7	0.9
A in %	40.5	27.4	1.5	15.3	71.9	43.4	11.5	3.8***	31.3	56.3
C in %	22.8	22.5	1.0	4.1	67.2	23.2	9.7	2.4*	11.8	40.6
E in %	35.3	8.4	4.2***	25.4	46.5	31.7	3.7	8.7***	27.0	36.7
Mother’s education										
Constant	2.9	0.2	16.4***	2.6	3.3	2.5	0.1	47.2***	2.4	2.6
Mother’s educ.	-0.1	0.0	-3.7***	-0.1	0.0	-0.1	0.0	-6.0***	-0.1	0.0
Total var.	0.8	0.1	10.4***	0.7	1.0	0.8	0.0	22.0***	0.7	0.9
A in %	37.7	27.0	1.4	13.0	71.1	43.4	11.6	3.8***	31.2	56.3
C in %	20.6	21.5	1.0	3.2	66.8	18.9	9.7	2.0*	7.8	38.9
E in %	35.2	8.6	4.1***	25.2	46.6	31.8	3.7	8.7***	27.1	36.8
R ² in %	6.6					6.0				
Net household equivalent income										
Constant	2.5	1.1	2.2*	0.3	4.6	3.5	0.4	10.2***	2.8	4.2
Net HH equiv. inc.	0.0	0.2	0.3	-0.2	0.3	-0.2	0.1	-3.3***	-0.2	-0.1
Total var.	0.8	0.1	10.4***	0.7	1.0	0.8	0.0	22.0***	0.7	0.9
A in %	40.7	27.4	1.5	15.5	72.0	42.6	11.5	3.7***	30.4	55.7
C in %	22.3	22.5	1.0	3.8	67.6	22.4	9.6	2.3*	11.0	40.1
E in %	35.3	8.4	4.2***	25.4	46.5	31.9	3.7	8.7***	27.2	37.0
R ² in %	1.8					3.1				
N _{Pairs}	110					630				

Table 2. *Continued*

	One parent					Two parents				
	<i>b</i> / <i>var</i>	c.s.e	<i>z</i> -value	95% CI		<i>b</i> / <i>var</i>	c.s.e	<i>z</i> -value	95% CI	
Math academic self-concept										
Constant	-0.1	0.1	-0.8	-0.2	0.1	0.0	0.0	1.2	0.0	0.1
Total var.	0.7	0.1	15.1***	0.6	0.8	0.6	0.0	37.7***	0.5	0.6
A in %	22.6	32.7	0.7	1.7	83.2	49.9	4.6	10.8***	45.4	54.4
C in %	22.0	25.7	0.9	2.8	73.7	-	-	-	-	-
E in %	55.5	12.0	4.6***	45.0	65.6	50.0	4.2	12.0***	45.9	54.0
Mother's education										
Constant	-0.1	0.1	-0.8	-0.2	0.1	0.0	0.0	0.8	0.0	0.1
Mother's educ.	0.0	0.0	1.2	0.0	0.1	0.0	0.0	1.3	0.0	0.0
Total var.	0.7	0.1	15.1***	0.6	0.8	0.6	0.0	37.7***	0.5	0.6
A in %	21.2	32.7	0.7	1.3	84.7	49.8	4.6	10.8***	45.3	54.3
C in %	22.4	25.6	0.9	3.0	73.0	-	-	-	-	-
E in %	55.9	12.1	4.6***	45.3	65.9	50.0	4.2	12.0***	45.9	54.0
<i>R</i> ² in %	0.5					0.3				
Net household equivalent income										
Constant	0.1	0.7	0.2	-1.2	1.5	-0.6	0.2	-2.5*	-1.0	-0.1
Net HH equiv. inc.	0.0	0.1	-0.3	-0.2	0.2	0.1	0.0	2.6**	0.0	0.1
Total var.	0.7	0.1	15.1***	0.6	0.8	0.6	0.0	37.7***	0.5	0.6
A in %	22.6	32.7	0.7	1.7	83.2	49.3	4.6	10.7***	44.7	53.9
C in %	21.8	25.7	0.9	2.7	73.8	-	-	-	-	-
E in %	55.5	12.0	4.6***	45.0	65.6	50.1	4.2	12.0***	46.0	54.1
<i>R</i> ² in %	0.1					0.7				
<i>N</i> _{Pairs}	143					806				

Notes: Clustered standard errors are calculated at the twin pair level. Source: TwinLife. † $p(Z > |z|) < 0.10$. * $p(Z > |z|) < 0.05$. ** $p(Z > |z|) < 0.01$. *** $p(Z > |z|) < 0.001$ (two-tailed tests).

and 50%, respectively). Although the trend for math grades is similar to cognitive ability and academic self-concept, the differences we find by family structure tend to be negligible: 41% in one-parent families and 43% in two-parent families.

For shared environmental influences, the results tend in the opposite direction. For cognitive ability, shared environmental influences were 13 percentage points lower in one-parent compared to two-parent families (27% and 14%, respectively), and for math academic self-concept, shared environmental influences were only evident and substantial in size in one-parent families (22%). Only for math grades, differences in shared environmental influences are negligible. In sum, our results revealed a clear pattern corresponding with our first hypothesis for cognitive ability and academic self-concept as the relative importance of genetic influences was higher in two- compared to one-parent families.

In the next step, we tested to what extent differences in the relative importance of genetic and shared environmental influences are associated with socioeconomic differences by adjusting the models for educational or financial differences. The results showed that mother's education had a positive impact on children's cognitive ability and math grades in both one- and two-parent families (see Table 2). However, mother's education did not affect children's math academic self-concept. For all three outcomes, we found that household income had a positive impact in two-parent families.

For cognitive ability, we found that mother's education explained about 13% of the total variance in one-parent families and only about 5% in two-parent families (see Mother's education, Figure 2 and Table 2). Adjusting for mothers' education reduced shared environmental influences and to a lesser extent genetic influences. In one-parent families, shared environmental influences accounted for about 18% (unadjusted 27%) of the total variation, and

genetic influences for roughly 27% (unadjusted 32%). In two-parent families, the relative importance of genetic influences remained nearly the same and explained about 46% of the total variation, while shared environmental influences decreased and accounted for about 10% (unadjusted 14%). If differences in mothers' education were driving the differences in the heritability of cognitive skills between single- and two-parent households, then mothers' education would have explained a larger part of the total variance and reduced the relative importance of genetic influences to a stronger extent. However, the genetic influences remained almost stable after adjusting for mothers' education, and differences in mothers' education therefore did not seem to account for the differential heritability of cognitive ability.

Household income explained less of the total variation in cognitive ability than mother's education: only about 1% of the variation in cognitive skills in one-parent and about 3% in two-parent families. Consequently, we found no substantial changes in the relative importance of genetic and shared environmental influences compared to models without the adjustment for household income. In sum, adjusting for mother's education and the financial situation of the household did not alter our base findings as substantial differences in the importance of genetic influences remained.

For math grades, we found a less pronounced pattern as for cognitive ability. Adjusting for mother's education explained about 7% of the total variance in math grades in one-parent families and 6% in two-parent families. Again, household income explained less of the total variance (about 2% in one-parent and 3% in two-parent families). Both the relative importance of genetic influences and shared environmental decreased somewhat once adjusted for mothers' education in one-parent families, while only the relative importance of shared environmental influences was lowered in two-parent families. However, the differences continue to be negligible once controlled for mothers' education or household income.

Results for math academic self-concept showed that shared environmental and genetic influences remained almost unaffected when adjusted for mother's education and household income. The unadjusted results that showed substantial differences in genetic influences on math academic self-concept by family composition

remained after adjusting for socioeconomic differences: genetic influences were consistently about twice as large in one- compared to two-parent families.

Taken together, the findings showed that differences in children's chances to realize their genetic potential existed net of differences in educational and economic resources. The results for cognitive ability and academic math concept support our second hypothesis: differences in the relative importance of genetic influences relevant for indicators of school performance by family structure are not driven by socioeconomic differences alone. While differences by family structure were negligible for math grades, our results for cognitive ability and academic math concept clearly support for our expectation that parental separation affects the quality of the family environment due to distinct processes over and beyond socioeconomic differences, and leads to the suppression of genetic influences among children whose parents separated.

CONCLUSION

In this study, we sought to ascertain (a) whether parental separation lowers children's chances to realize genetic dispositions relevant for school performance and (b) whether differences in heritability are driven by socioeconomic differences between two- and single-parent households. We studied genetic influences on three different indicators of school performance – cognitive skills, math grades, and math academic self-concept – that are important predictors for children's educational attainment. Drawing on previous findings that show that parental separation can have a negative impact on children's school performance and enhancement theories rooted in behavioral genetics, we expected genetic influence on school performance to be higher in two-parent compared to single-parent families (H1). Furthermore, if parental separation moderates the impact of genetic influences due mechanisms above and beyond socioeconomic differences between households, then genetic influences on school performance should be lower in one-parent compared to two-parent families even when adjusted for parental education and household income (H2).

Our results supported both hypotheses and provided a clear pattern for cognitive ability and math academic self-concept. Genetic influences

accounted for substantially more variance in children's school performance in two-parent compared to one-parent families. Furthermore, the higher genetic influence in two-parent compared to one-parent families is not attributable solely to educational or income differences between households, but likely driven by mechanisms related with family instability. Specifically, our findings support the notion that processes associated with parental separation, such as more distant parenting, reduced parental monitoring, and higher levels of stress among children, lower the quality of the family environment (e.g., Cooper et al., 2011; Hadfield et al., 2018; Lee & McLanahan, 2015). Compared to the tailored environments of two-parent households, the environments of children in single-parent households seem less able to enhance children's chances to realize their genetic potential. Our results for cognitive ability and math academic self-concept therefore support the expectation that parental separation indeed represents a distinct set of environmental conditions that moderate the impact of genetic influences although further research is needed to adjudicate the mechanisms at work.

For math grades differences in the heritability between one- and two-parent households were negligible. One possible explanation for our math grade findings could lie in the highly stratified and differentiated German school system, which makes it difficult to compare school grades across different school types. While we controlled for the school type, we are likely not able to completely capture differences with respect to grading. For example, it's more difficult to obtain the best grade in the most demanding school tracks ("Gymnasium") compared to lower tracks ("Hauptschule" and "Realschule"). Future research on school grades should therefore choose a country with a comprehensive schooling system that facilitates comparability. In addition, grades are plagued by slightly higher missingness compared to our other indicators. Therefore, our findings on grades should also be replicated once larger data sets are available for Germany.

Our study highlights promising avenues to facilitate a better understanding of heritability differences in children's school performance by family structure. For example, further research is needed to examine whether the impact of parental separation differs by children's age, because children's vulnerability for negative life

events may vary over their childhood. Children rely almost exclusively on familial resources during early childhood, whereas more proximal contexts, such as schools, teachers, or peers, become more influential as children grow older. In sum, to gain a better understanding on the link of parental separation and genetic influences, future research needs to study different outcomes, while accounting for the timing of parental separation as well as the duration of exposure to marital conflict.

In addition, future research should examine the diversity of single- and two-parent households in greater detail. For example, we were not able to include step-parent families in this study. However, research on family instability highlights that divorce is one of many transitions that may affect children negatively (Cavanagh & Fomby, 2019; Hadfield et al., 2018). Future research is needed, for example, to examine to what extent the presence of a step-parent changes the quality of the family environment. An additional adult in the household may be able to help facilitate a rearing environment tailored to the needs of children and thereby help children express their genetic potential. In contrast, stress and conflict associated with remarriage and merging two households may further suppress the realization of children's innate abilities. More information on the socioeconomic well-being of households than household income and mothers' education, such as occupation status, as well as indicators of family processes, such as custody arrangements and father involvement, are needed to capture all the latent constructs that should be considered.

In addition, our findings refer to Germany, often considered an ideal typical conservative welfare state that provides a relatively high level of social security. However, German labor market and family policy also actively incentivizes a male-breadwinner female-homemaker division of labor with low coverage of all-day childcare and schooling. Differences in the realization of children's genetic potential by household composition may be larger in liberal societies, such as the United States, where women are at a considerably higher risk of poverty following divorce (Van Winkle & Struffolino, 2018). Compared to social democratic states where social systems secure divorced women's socioeconomic well-being and facilitate labor market participation, such as Sweden, differences in the heritability may be lower. Future research

should estimate the heritability of school-related skills by household composition in other contexts to gain insight on the extent that institutional arrangements ameliorate or exacerbate the effects of parental separation.

One limitation of our study lies in the CTD and its inability to account for gene–environmental correlations. Previous research shows that parental divorce itself is heritable, with estimates ranging from 0.13 to 0.50 (McGue & Lykken, 1992; Salvatore et al., 2018). If genetic influences that affect parental separation also affect children’s school performance, for example, via problem or nonconfirmatory behavior in school, then the link between parental separation and children’s school performance would be genetically confounded (e.g., Jaffee & Price, 2007). To date, several studies have investigated to what extent gene–environment correlations drive the impact of separation or divorce (see for an overview Amato, 2010). These studies have used adoption- or children of twin (CoT) designs. Previous research shows that negative influences on abnormal behavior are driven by environmental exposure, while evidence is mixed for internalizing problems and educational outcomes (e.g., D’Onofrio et al., 2005, 2006, 2007). Although O’Connor et al. (2000) provided evidence for gene–environment correlations for reading competencies, parental reports on children’s achievement, and children’s self-reported attitudes about educational achievement, D’Onofrio et al. (2006) provided conflicting evidence for grade repetition and years of education. In light of the weak support for gene–environmental correlations, the current literature indicates that gene–environmental correlations are likely not the main driver of the association between parental separation and children’s outcomes.

Another promising route for future research is to examine whether the negative impact of parental separation is driven by genetic nurturing (e.g., Dalton & Fletcher, 2017; Kong et al., 2018; Liu, 2018). Genetic nurturing describes how genetic influences that are not passed down to children still affect their outcomes. For example, it could be that specific genes that are associated with parental separation are also associated with specific parenting behaviors. Even if these genes are not transmitted they could still affect children as they lead to specific parenting behavior. Such research questions, however, can only be

addressed using methodological approaches developed in molecular genetics.

In conclusion, our study has for the first time shown that genetic influences on certain indicators of children’s school performance differ considerably in single- and two-parent families. In addition, our findings indicate that parental separation is associated with processes that affect the realization of children’s genetic potential above and beyond socioeconomic differences. Our study highlights an important but until now mainly neglected factor in the intergenerational transmission of disadvantage among children who experienced a parental separation and live in single-parent households (McLanahan, 2004; McLanahan & Percheski, 2008; Raley & Sweeney, 2020). Our study has implications for policies targeted at improving the educational disadvantages of children living in single-parent households. For example, tailored learning environments within and outside of schools targeted at children living in single-parent households could complement income transfers to ensure children’s chances for the realization of their genetic potential. A shift from traditional structural characteristics to family structure is needed to enhance our current understanding on the mechanisms behind the gene–environment interplay leading to the reproduction of inequalities across generations.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Supporting Information.

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