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Original Article

Socioeconomic Background and Gene–Environment Interplay in Social Stratification across the Early Life Course

Jani Erola [1,*], Hannu Lehti [1], Tina Baier[2] and Aleksi Karhula[1,3]

[1]Department of Social Research, University of Turku, Turku 20014, Finland, [2]Department of Sociology and Human Geography, University of Oslo, 0317 Oslo, Norway and [3]Ecosystems and environment research programme, University of Helsinki, Helsinki 00014, Finland

*Corresponding author. Email: jani.erola@utu.fi

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Abstract

To what extent are differences in education, occupational standing, and income attributable to genes, and do genetic influences differ by parents' socioeconomic standing? When in a children's life course does parents' socioeconomic standing matter for genetic influences, and for which of the outcomes, fixed at the different stages of the attainment process, do they matter most? We studied these research questions using Finnish register-based data on 6,529 pairs of twins born between 1975 and 1986. We applied genetically sensitive variance decompositions and took gene–environment interactions into account. Since zygosity was unknown, we compared same-sex and opposite-sex twins to estimate the proportion of genetic variation. Genetic influences were strongest in education and weakest in income, and always strongest among those with the most advantaged socioeconomic background, independent of the socioeconomic indicator used. We found that the shared environment influences were negligible for all outcomes. Parental social background measured early during childhood was associated with weaker interactions with genetic influences. Genetic influences on children's occupation were largely mediated through their education, whereas for genetic influences on income, mediation through education and occupational standing made little difference. Interestingly, we found that non-shared environment influences were greater among the advantaged families and that this pattern was consistent across outcomes. Stratification scholars should therefore emphasize the importance of the non-shared environment as one of the drivers of the intergenerational transmission of social inequalities.

Introduction

The importance of the socioeconomic rearing environment at specific periods during childhood and youth is well established in the research literature (Duncan, Brooks-Gunn and Klebanov, 1994; Esping-Andersen, 2002; Heckman, 2006; Burger, 2010). However, empirical evidence suggests that variations in these conditions, either by children's age or according to the type of family resources available, are of little importance for the outcomes on which social stratification research tends to focus, such as educational and socioeconomic attainment (Conley and Glauber, 2007; Erola, Jalonen and Lehti, 2016; see also Adermon, Lindahl and Waldenström, 2018; Hällsten and Thaning, 2018).

Why is there such persistence? One often ignored explanation is genes, a type of endowment that we receive from our parents that is relatively fixed for life. The associations between parents' socioeconomic resources and children's socioeconomic outcomes may simply be correlated because the genes we received from our parents had an impact on how well they succeeded in life, and therefore had the same effect on us. The importance of parents' socioeconomic resources could vary only inasmuch as they are not associated with genetic influences common to parents and children. However, it is also possible that differences in the importance of parents' resources over children's life courses are hidden because the interplay between genetic influences and the rearing environment is ignored. The sibling methods typically applied in the literature cannot distinguish genetic influences from other shared effects related to family background. There is little research on how changes in socioeconomic rearing environment during childhood and youth are shown in gene–environment interplay, especially in the case of socioeconomic outcomes.

In this article, we acknowledge that the intergenerational transmission of social inequalities comprises both social and genetic pathways that are interrelated.

Extending the scope from social stratification research to behavioural genetics, we address the following research questions: (i) to what extent are differences in children's education, occupational standing, and income attributable to genes?; (ii) do genetic influences differ by parents' socioeconomic standing; (iii) when in the children's life course does parents' socioeconomic standing matter for the genetic influences; and (iv) for which of the outcomes, fixed at the different stages of the attainment process, do genetic influences matter most?

We analysed high-quality twin data acquired from Finnish administrative registers. Using full population data, we concentrated on birth cohorts born 1975–1986, covering 6,529 twin pairs. We applied genetically sensitive variance decomposition methods (ACE models) with extensions that allowed us to examine the gene–environment interplay (e.g. Purcell, 2002; Guo and Stearns, 2002). In the absence of zygosity information, the importance of genetic influences was estimated through comparisons between same-sex and opposite-sex twins (e.g. Figlio *et al.*, 2017).

As outcomes, we compared educational attainment at age 28, occupation-based status attainment observed around age 32, and log mean income at age 32–36. We measured parents' socioeconomic status (SES) with education, occupation, and income at different stages of early childhood. We analysed each indicator of parents' SES independently and assessed their joint influence using a composite index of SES.

Our findings can be linked to the debate on the association between equality of opportunity and genetic inheritance. Previous research indicates that family background matters relatively little in Finland compared to other countries (Björklund and Jäntti, 2000). However, many believe that stronger equality of opportunity should boost genetic influences in intergenerational attainment (Guo and Stearns, 2002; Engzell and Tropf, 2019). If that is the case, these influences should be particularly strong in Finland.

We provide new insights on how socioeconomic differences in family environments may continue to matter over, and sometimes above, the genetic influences, even in highly egalitarian institutional settings. Previous studies have analysed single indicators of socioeconomic attainment, such as education and income, but there have been no previous systematic comparisons between the three outcomes or between the different stages of the early life course.

Social Stratification of Genetic Influences on Socioeconomic Outcomes

One of the main assumptions of the social stratification literature is that a more resourceful family environment during childhood leads to better socioeconomic outcomes in adulthood. It is often assumed that children benefit from their parents' resources in two different ways: through *endowments* and *investments* (Becker and Tomes, 1986; Musick and Mare, 2006; Esping-Andersen, 2015). Investments refer to parents' efforts to have a positive impact on their children's outcomes, for instance, by using their time or money for parenting, and are dependent on the resources available to the parents. Endowments, on the other hand, refer to the resources and assets available for children in their rearing environment, such as social networks and economic assets. Different investments and endowments are often correlated, and the ways in which they contribute to socioeconomic outcomes together can vary considerably. The positive effects can only be additive and accumulate, they can boost or even multiply each other's impact, or the lack of some resources can be compensated with others that are available (Erola and Kilpi-Jakonen, 2017).

What has often been neglected in this literature is that endowments also include inherited genetic influences. If considered, genetic and social influences have been mostly treated as competing forces, best shown in the *nature vs. nurture* debate (Murphy, 1995). More recently, however, scholars have become increasingly aware of the interdependence of genetic and environmental influences on status-related outcomes (Guo and Stearns, 2002; Shanahan and Hofer, 2005; Freese, 2008).

There are two different approaches describing the gene–environment interplay: *gene–environment interactions (GxE)* and *gene–environment correlations (rGE)* (Scarr and McCartney, 1983; Dick, 2014). GxE describes situations in which the environmental influences moderate genetic influences. rGE acknowledges that the environments that individuals encounter can be dependent on genetic dispositions.

Shanahan and Hofer (2005) proposed an often-used typology to map the different processes underlying GxE. The first of these is *enhancement*, the positive multiplicative processes between genes and environment where specific aspects of the environment further the realization of favourable genetic dispositions. C*ompensation* refers to cases where environmental processes cancel out potentially negative genetic influences. *Triggering* refers to a situation where negative genetic influences are triggered by negative events or stressors. Finally, *social control* describes how shared norms or values constrain behaviour and choices and restrict the realization of genetic influences.[1]

Given the focus of the social stratification literature on the positive effects of more resources in childhood, the type that is most relevant for this study is enhancement: this means that socioeconomically advantaged rearing conditions boost the positive genetic influences relevant to offspring's education, occupation, and income (Shanahan and Hofer, 2005). For instance, more educated parents may have both high educational expectations and sufficient economic resources to provide a learning-stimulating home environment that helps children to fulfil their genetic potential (cf. Baier and Lang, 2019). The positive interaction between parents' social background and genetic influences was originally described in the Scarr-Rowe hypothesis, which postulates that genetic effects on IQ are stronger among the advantaged (Scarr-Salapatek, 1971).

Thus, our first hypothesis (*H1*) is:

H1: Genetic influences on status-relevant outcomes are greater among children from advantaged families than children from disadvantaged families.

Additionally, other types of GxE can lead to a similar pattern. For instance, a disadvantaged social background can *constrain* the realization of genetic potential, thus leading to lower genetic influences among disadvantaged families (Guo and Stearns, 2002). If this constraining followed from aspirations being stratified by parents' SES (Zimmermann, 2020), this would mean that *social control* was also involved.

Several studies have considered the hypothesis in the context of outcomes that are closely related to those studied here, such as IQ or cognitive skills (e.g. Guo and Stearns, 2002; Turkheimer *et al.*, 2003; Figlio *et al.*, 2017; for meta-analyses, see Tucker-Drob and Bates, 2016; Peng *et al.*, 2019). However, research on socioeconomic outcomes is much more limited and has yielded inconclusive results. For example, Baier and Lang (2019) found that in Germany, better educated parents were associated with stronger genetic influence on education; in the United States, Domingue *et al.* (2015) found a similar pattern of stratification according to the mother's education. However, Conley *et al.* (2015) did not find evidence for gene–environment interaction with mother's education, whereas Lin (2020) found that genes mattered more in the lower social strata, and Belsky *et al.* (2018) found mixed evidence for enhancement in socioeconomic attainment in three different US-based studies and no evidence in New Zealand.

Timing of Investments and Endowments over Children's Early Life Course

At which point during childhood do parents' investments and endowments matter? The literature indicates that the socioeconomic rearing environment during early childhood can be highly consequential. Previous research found that poverty and the lack of stimulation of cognitive skills during this period can hamper the development of various socioeconomic outcomes shown later during the life course (Duncan, Brooks-Gunn and Klebanov, 1994; Esping-Andersen, 2002; Heckman, 2006; Burger, 2010). During early childhood, children rely almost exclusively on parents as providers of their environment. Given that both endowments and investments are likely to depend on parents, we can expect the stratification of genetic influences by parental socioeconomic characteristics to be strong from the early years onwards.

Processes related to rGE, the situations in which environmental exposure depends on genetic dispositions, can contribute to the importance of early socioeconomic rearing environments (Plomin, DeFries and Loehlin, 1977; Scarr and McCartney, 1983). *Passive* rGE refers to a situation where parents provide both the rearing environment and genes to the children. For example, even if highly educated parents also provide a more stimulating home environment, it would be the inherited cognitive skills that had a positive impact on children's educational attainment: thus, the association between the environment and children's outcomes would be spurious and largely driven by genetic endowments.

In addition, parents' investments can be affected by the genetic dispositions of the children, referred to as *evocative* (or *reactive*) rGEs. For instance, parents may support children's engagement in certain sports where children are particularly skilled and discourage participation in the sports in which their children do not seem to have talent. As children grow older, they become increasingly exposed to wider social environments, where both new endowments and investments of others may become more important. Consequently, parental investments may become less important.

This process can be accelerated by *active* rGE, according to which children seek environments that are suitable for their own genes (Plomin, DeFries and Loehlin, 1977). For example, adult children may find a specific field of study that fits with their own talents and follow that educational pathway—even if their parents never supported that choice. Active rGE should be expected to become stronger over the life course as children gain independence (Tucker-Drob and Harden, 2012; Shanahan, Mortimer and Johnson, 2016).

Thus, the environment depends more on parents when children are younger and self-selection to the environments fitting best with children's own genetic potential becomes more important as they become older. Therefore we expect the following:

H2: The younger the children are when parental characteristics are observed, the stronger is the social stratification of genetic influences.

Differences across Socioeconomic Outcomes

Gene–environment interplay could also differ by outcome, depending on when in the life course attainment takes place. Educational careers begin very early in childhood, and their maturity also tends to be achieved earlier (before age 30) than in the case of other socioeconomic outcomes (cf. OECD, 2014). Occupational careers do not usually begin before age 20 and maturity is reached at approximately age 35 (Härkönen, Manzoni and Bihagen, 2016). Regarding income, maturity is achieved even later, with substantial variation by country, at around age 40 in the United States and after age 50 in Finland (Cheng and Song, 2019; Karonen and Niemelä, 2020). The same processes that may underlie Hypothesis 2—the younger the child, the more the parents contribute to the environment, and increasing self-selection to environments fitting best with children's own genetic potential over time—leads us to expect that the types of socioeconomic attainment that are fixed earlier in the life course are also more strongly stratified than those fixed later.

The temporal order of the types of attainment should strengthen this pattern. The relationships between education, occupation, and income over the individual life course are likely to be unidirectional; income is not likely to have an impact on occupation, nor occupation on education (Erola, Jalonen and Lehti, 2016; Lahtinen, Erola and Wass, 2019). Thus, unless taken into account, the consequent forms of social stratification are likely to reflect the previous stages of the attainment process. For example, education could mediate genetic influences on occupational standing. Accordingly, our third hypothesis (*H3*) is as follows:

H3: Genetic influences in later socioeconomic outcomes run through the socioeconomic attainment achieved earlier.

In the behavioural genetics literature, this phenomenon is referred to as *mediated pleiotropy* (Wedow *et al.*, 2018). This hypothesis is supported by earlier research: Marks (2017) found that in Australia, the genetic influences in income run principally through education and occupational standing. Education and occupation seemed to share largely the same genetic influences, as was the case for occupation and income, but this was much less so between education and income.

However, the same genetic influences could also have an impact on two outcomes directly, thereby constituting a shared factor behind the observed correlation between them, or alternatively through a third factor linked to both. This is referred to as *biological pleiotropy*. In our case, the genetic influences on both occupation and income could run through education, rather than genetic influences of education being transmitted to income through occupation.

Institutional Context

We study the hypotheses using register data from Finland. Traditionally, Finland has been considered a society with a high level of equality of opportunity, meaning that parental SES determines children's adult socioeconomic outcomes relatively weakly. This has been found to be true for various socioeconomic outcomes, including education, occupational status, and income (Björklund and Jäntti, 2000; Erola, 2009; Grätz *et al.*, 2019).

The importance of genetic influences is often measured as *heritability*, the proportion of a variation in an outcome or phenotype attributable to differences in genetic variation (h^2). Some scholars argue that heritability in socioeconomic attainment should be considered a measurement of equality of opportunity (Heath *et al.*, 1985; Guo and Stearns, 2002; Nielsen, 2006). The extent to which individuals can realize their genetic potential is seen as an indicator of a society's openness. Therefore, we should expect that when the effects of social origin are weak, genetic inheritance would be strong. Recent empirical evidence supports this assumption. Engzell and Tropf (2019) studied children in 10 western industrialized countries born in the 1940s to 1980s and demonstrated that heritability rises with educational mobility; thus, equality of opportunity in education increases.

However, high heritability is not necessarily closely associated with equality of opportunity. It can also reflect the genetic influences of ascribed characteristics such as skin colour, attractiveness, height, and sex, all of which clearly violate the equal opportunity assumption (Diewald *et al.*, 2015): The 'genetic lottery' of not being able to pick one's own genetic makeup but being forced to inherit them from parents is often considered contrary to the principles of equal opportunities (Rawls, 1971).

Therefore, it is not surprising that another study of education in 28 countries did not show that greater openness would lead to stronger influence of genes, whether in terms of change over time or by country differences (Silventoinen *et al.*, 2020). Rather, both genetic and shared environmental influences weakened over time. This is to be expected in countries where social institutions aim to reduce the importance of some ascribed characteristics and increase fairness. In Finland, such institutions include, for example, high-quality early childcare (Karhula, Erola and Kilpi-Jakonen, 2017) and free-of-charge educational systems (Pekkarinen, Pekkala and Uusitalo, 2006; OECD, 2008).

The heritability of education and income has been previously studied in Finland. In the case of twins born in 1936–1955, Silventoinen *et al.* (2004) found that it was approximately 48% for men and 45% for women; the shared environment accounted for approximately 40%. Nisén *et al.* (2013), studying birth cohorts from the 1950s, found that the heritability of education was somewhat smaller and almost the same across genders (around 42%), but that the shared environmental factors were stronger for women (54% vs. 37% of men). In the case of lifetime labour earnings, heritability was about 40% among women and over 50% among men in the birth cohorts from the 1950s, while the contribution of the shared environment was negligible (Hyytinen *et al.*, 2019).

The Finnish findings are similar to results from other Nordic countries sharing similar institutional settings. In Norway, Heath *et al.* (1985) found that among the twins born in 1940–49, heritability in education was as high as 74% among men and only 45% among women, whereas for those born in 1950–60, the equivalent numbers were 67% and 38%. Ørstavik *et al.* (2014) discovered that the heritability of education was 40% and for women 50% among twins born in 1967–79, overlapping with the findings of Lyngstad, Ystrøm and Zambrana (2017). Silventoinen *et al.* (2020) reported a similar pattern of weakening heritability between older and younger Swedish twin cohorts. Ørstavik *et al.* (2014) also reported the heritability of income for men to be 46% for men and 42% for men.

Data and Methods

We tested our hypotheses using high-quality twin data acquired from Finnish administrative registers, which covered the entire Finnish population and thus included all twins who were alive during the period 1987–2016.[2] In this study, we focused on those born between 1975 and 1986. These birth cohorts include all twins that we can follow from early childhood to adulthood in our data. The data cover socioeconomic information on twins and their parents in 1975, 1980, 1985, and annual information from years 1987 to 2018.

We compared results across three outcomes: the highest level of education measured in years by age 28; occupation-based SES at age 30, utilizing the International Socio-Economic Index of Occupational Status (ISEI); and log mean annual income at age 32–36. Income included all individual annual earnings, capital income, and income transfers after taxation. When we accounted for the socioeconomic characteristics of the parents, we used similar indicators recorded in the registers at the five stages of the early life course of the children. These stages were: age 0–5 (pre–school); age 6–10 (early elementary school); age 11–15 (late elementary school); age 16–20 (secondary education); and age 21–25 (after secondary education). For parents' education and ISEI, we used the dominance principle and took into account the highest value for each of the biological parents. Parents' ISEI was divided into quintiles. Their education had four levels: (i) basic or less, (ii) vocational/general secondary, (iii) post-secondary/lowest tertiary, and (iv) bachelor's degree or higher. For income, we took into account the incomes of both parents and split them into quintiles.

Furthermore, to test the life course hypothesis, we constructed a composite index accounting for all parental socioeconomic characteristics. We applied the information on education, occupation, and income on parents from all stages of childhood and youth in principal component analysis (PCA). This provided us with a joint indicator of social background that changes between the stages of the early life course if any of the components of the index change. More detailed information on the PCA can be found in Supplementary Appendix Table A2.

We omitted twins with missing information on occupation (7%), those with missing or zero income (3%), and those with missing information on parents' socioeconomic characteristics (2%). Our final analytical sample included 6,529 twin pairs.

We applied the classical twin design (CTD, Plomin *et al.*, 2008) to estimate genetic influences. While dizygotic (DZ) twins share on average 50% of their DNA, monozygotic (MZ) twins are genetically identical. This information can be used to decompose the total variance of an outcome into a variance component associated with additive genetic influences (A), shared environmental influences (C), and non-shared environmental influences (E). E also includes the error term of variance decomposition. The measurement errors can be expected to be much smaller in the registers than in the surveys. This method is known as the ACE model.

The identification of genetic and environmental influences is based on additional assumptions (Plomin *et al.*, 2008). First, ACE models identify additive genetic effects. It is assumed that genetic effects on phenotypes (outcomes) do not interact with each other (no epistasis). Non-additive genetic influences do not greatly matter for complex traits such as education, occupation, and income (e.g. Mills, Barban and Tropf, 2020). The second assumption is the equal environment assumption (EEA) (Scarr and Carter-Saltzman, 1979), which states that MZ and DZ twins are similarly treated by their environment (e.g. parents, peers, or friends). If EEA is violated, heritability estimates tend to be inflated because the similarity of MZ twins is then driven by a more similar treatment of their surroundings and not due to their genes. EEA has been tested for several outcomes, including those that are relevant for status attainment, and the results show that more similar treatment does not bias heritability estimates (Derks, Dolan and Boomsma, 2006; Conley *et al.*, 2015; Mönkediek, 2021).

The third assumption is that there are neither gene–environment interactions nor gene–environment correlations in the population for the specific trait. However, if these correlations and interactions are taking place but not taken into account, false conclusions will be drawn about the importance of genes and the environment (e.g. Purcell, 2002; Horwitz and Neiderhiser, 2011; Beam and Turkheimer, 2013). We relax this assumption by fitting models that assume interactions between each included variance component and the socioeconomic characteristics of the parents (Guo and Wang, 2002; Purcell, 2002).

Finally, the CTD assumes that there is no assortative mating among spouses. Random mating justifies the assumption that DZ twins (or siblings) share, on average, 50% of their DNA. If spouses are more similar according to the characteristics relevant for the studied trait, the genetic similarity of DZ twins or siblings is higher. As a consequence, genetic influences are underestimated and shared environmental influences are overestimated. Since assortative mating by education and ISEI is a well-established phenomenon in industrialized countries (Kalmijn, 1994; Blossfeld, 2009), we correct our analyses as suggested by Loehlin, Harden and Turkheimer (2009)[3] by adjusting the genetic correlation of DZ twins as follows: $0.5 + 0.5 * h_0^2 * r_p$, where h_0^2 stands for the heritability estimate without the correction for assortative mating and r_p is the correlation of spouses (here: education and ISEI). In our data, spousal correlation in education is 0.44 (0.42 for ISEI), leading to a genetic correlation for DZ twins of 0.59 for education and 0.58 for ISEI. Note that we did not adjust our estimations for income because shared environmental influences were absent.

A limitation of the data is that we do not know the twins' zygosity. To overcome this limitation, we followed previous research and used twins' gender to approximate their zygosity (Scarr-Salapatek, 1971; Pokropek and Sikora, 2015; de Zeeuw and Boomsma, 2017; Figlio *et al.*, 2017). Opposite-sex twins are all dizygotic, while same-sex sex twins can be either mono- or dizygotic. Relying on the assumption that same-sex (ss) and opposite-sex (os) twins are equally alike among dizygotic twins, we correct for the genetic correlation of ss as follows: (*ss* − *os*)/*ss* + 0.5 * *ss*/*os*. Applying this correction yields a genetic similarity of *ss* twins of approximately 0.76. While the chosen approach has been criticized of being less precise than having direct information on zygosity (e.g. Eaves and Jinks, 1972), previous comparisons suggest that this correction provides ACE components that are comparable to those acquired using information on zygosity (de Zeeuw and Boomsma, 2017). In addition, we standardized our outcomes by gender to account for a higher similarity of *ss* twins that might be induced by having the same sex (Figlio *et al.*, 2017).

The comparison of intraclass correlation coefficients of the *ss*- and *os*-twins to those of *ss*- and *os*-non-twin siblings (i.e. sibling correlations) are reported in the Supplementary Appendix Figure A1. They show that the similarity of same-sex twins is higher than that of opposite-sex twins and siblings. In addition, there were no substantial differences among same-sex female and same-sex male dyads. The comparison suggests that EEA should not bias our results substantively (for more details, see Supplementary Appendix Figure A1).

We estimate ACE components by using a multilevel parametrization described by Rabe-Hesketh *et al.* (2008). Structural equation modelling represents another common approach, but both types of modelling can be applied to retrieve identical estimates (Grilli and Rampichini, 2006; Rabe-Hesketh *et al.*, 2008).

To test our hypotheses, we first fitted ACE models (with and without the adjustment for assortative mating) to provide baseline estimates for the relative importance of genetic influences for all our outcomes. To test whether the magnitude of genetic influences differs by parents' social standing, we estimated non-parametric gene–environment interaction models for different socioeconomic subgroups of parents when children were aged 11–15 years (Guo and Wang, 2002).

In order to study whether it matters when in childhood the socioeconomic parental characteristics are measured, we fitted linear gene–environment interaction models to simplify the interpretation of the results (Purcell, 2002).[4] Each stage of the life course was modelled separately. These models included slopes for the interaction between genes and SES. For these analyses, we report the results only according to parental SES estimated with the composite index.

Finally, we tested the importance of the temporal order of the status attainment process. When testing the hypothesis on occupational standing, we controlled for education, and for income, we controlled both education and occupation. For these analyses, the results were provided again using the non-parametric version of the model where the subgroups were defined by the composite index when children were age 11–15.

We used the acelong (Lang, 2019) and gllam (Rabe-Hesketh, Skrondal and Pickles, 2004) commands in Stata to estimate our models. All appendices are reported in the Supplementary Material.

Results

Let us first consider how environmental and genetic influences contribute to education, occupation, and income. Figure 1 reports the results for our three outcomes of interest, where the left side shows the unadjusted baseline models and the right side presents them adjusted for assortative mating by parents' education. The bars in Figure 1 show how much of the total variation in each outcome can be attributed to genetic, shared, and non-shared environmental influences (as a percentage of the total variance). Absolute values for each variance component are reported in the Supplementary Appendix Table A1.

In the unadjusted models, we find that for education, the relative importance of genetic influences (*A*%) is about the same as the importance of non-shared environmental influences (*E*%) (i.e. 43% and 45%, respectively). For ISEI and income, genetic influences are less pronounced than those for the non-shared environment (E%) (55% vs. 37 for ISEI, 71% vs. 29% in the case of income). The relative importance of shared environmental influences (*C*%), however, is small for education and ISEI (13% and 8%), and absent for income. It is important to keep in mind that these estimations are population level parameters and therefore do not refer to individuals (cf. Diewald *et al.*, 2015). For instance, we find that 45% of the difference in education in Finland can be attributed to genetic influences, but this does not mean that 45% of a person's education is determined by genes.

When we adjust for assortative mating based on parents' education, *shared environmental influences* are substantially smaller and no longer statistically significant for education or ISEI (see Supplementary Appendix Table A1). This indicates that in Finland, families and the social institutions faced by the relatively recent birth cohorts provide rather equal rearing environments, allowing genes to unfold relatively freely. As shared environmental influences are essentially absent once assortative mating is taken into account, in our subsequent analyses, we estimated AE models instead of ACE models.

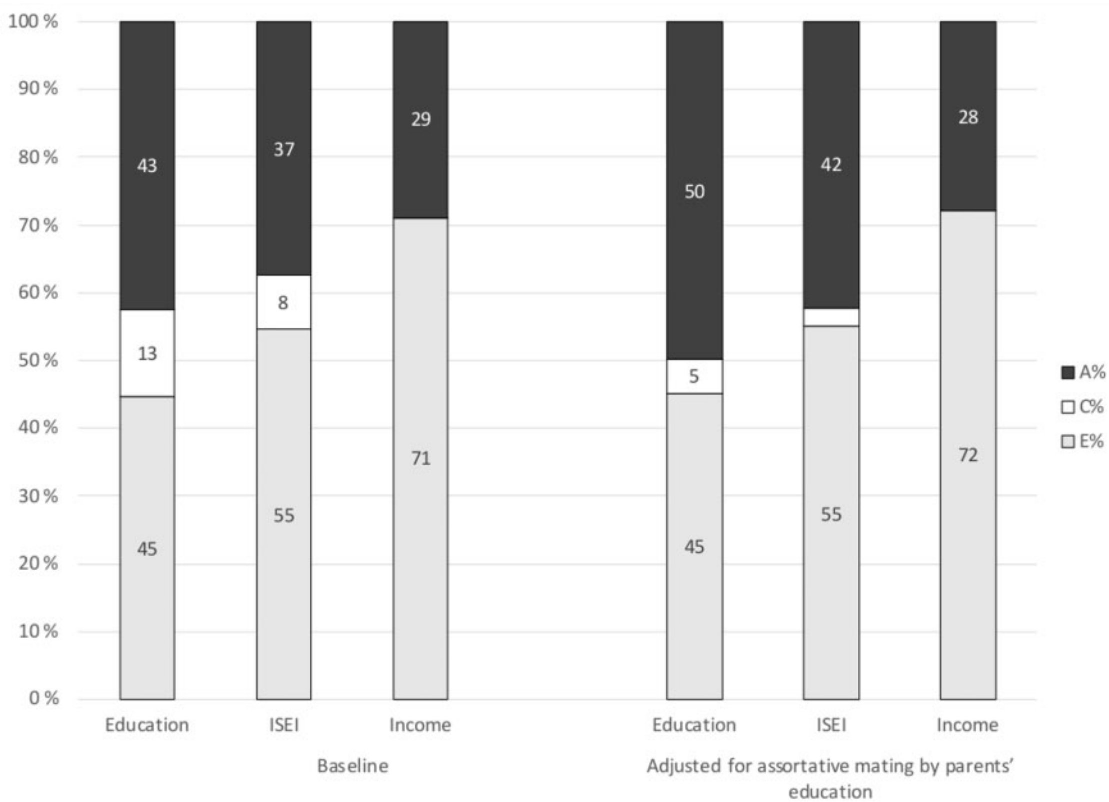

Figure 1. ACE components across different outcomes

We then tested our first hypothesis (*H1*). We propose that genetic influences are greater for children from advantaged families. We measured parents' SES with parents' education, ISEI, income, and the composite SES index. Figure 2 shows the variance components for *A* and *E* for each of the twins' outcomes (columns), by parental SES (rows). As the total variance changes across the subgroups, we present the findings in absolute variance components, and the findings for both absolute and relative values are presented in the Supplementary Appendix Tables A3a–A3d.

Starting with twins' education, we find that genetic influences are almost twice as large among the most advantaged families as in the lower parts of the distribution. This pattern is consistent across the different indicators of parental SES. However, the relationship between parental SES and the magnitude of genetic influences on education is not linear: It is only the most advantaged group that is clearly different from the others, and the differences between the remaining groups are substantially smaller. The same finding holds for twins' ISEI and income. To conclude, the findings support Hypothesis 1 to the extent that it refers to the difference between the most advantaged and others.

Interestingly, we find a similar but even more contrasting pattern in the case of non-shared environmental influences. Greater heterogeneity in the socioeconomic outcomes at the top end of the social strata is often observed when children of advantaged and disadvantaged groups are being compared (Goldstein and Warren, 2000; Heflin and Pattillo, 2006), and this seems to apply to both genetic and non-shared influences.

Our second hypothesis assumes that the younger children are when parental characteristics are observed, the stronger is the social stratification of genetic influences according to them (*H2*). Table 1 shows the absolute variance components *A* and *E* and the linear interaction terms (slopes) with the composite SES index, *A*' and *E*'. The main effect of *A* represents the magnitude of genetic influences for someone with average parental SES. The interaction term *A*' reveals to what extent genetic influences differ systematically by parents' SES and children's stage of the life course. Thus, *A*' indicates the strength of stratification.

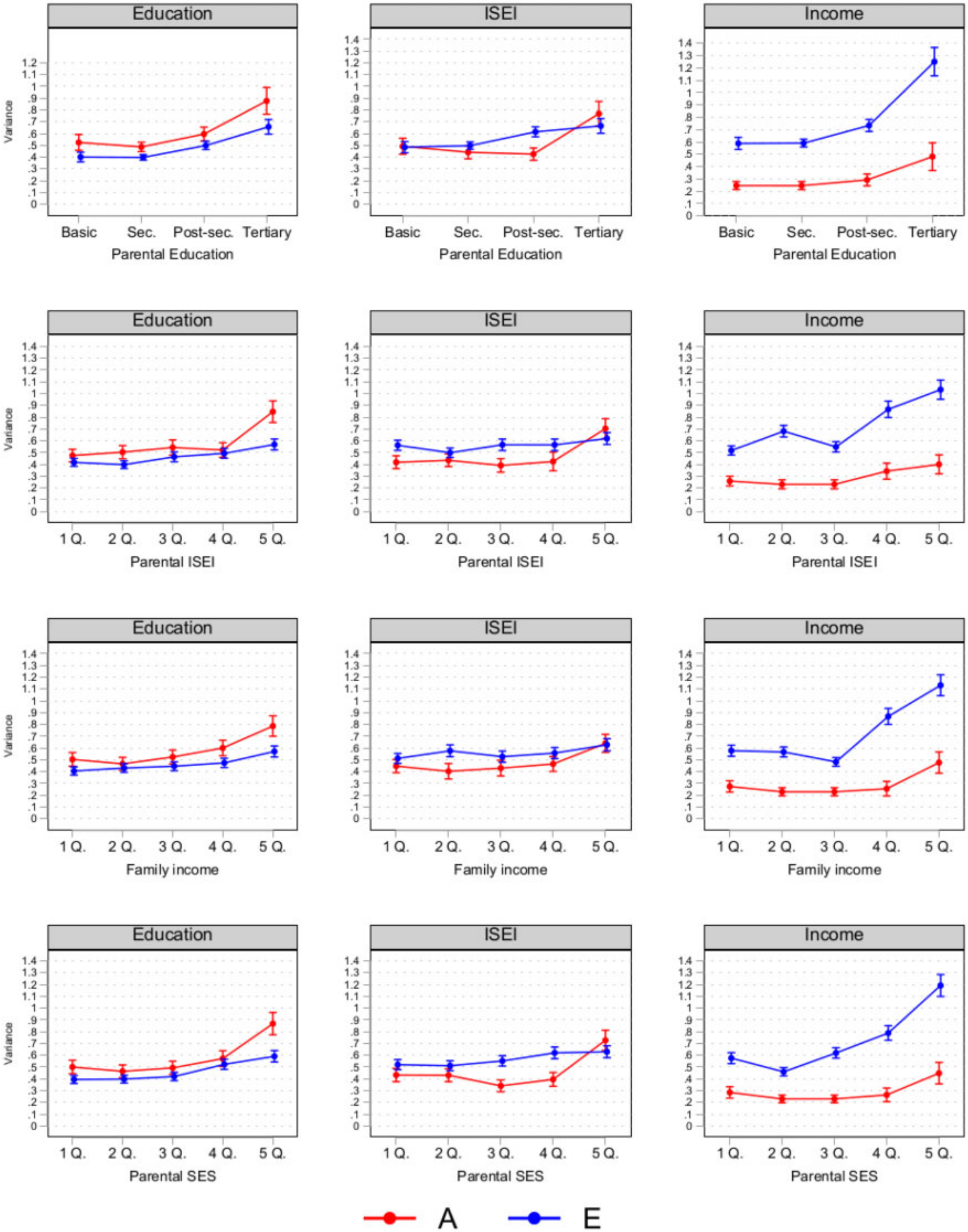

Figure 2. Variance components for *A* and *E* for each of the twins' outcomes (columns: education, ISEI, and income), by parental socioeconomic status (rows: education, ISEI, income, and the composite SES index)

Table 1. Variance components *A* and *E* (main effects) and linear interaction terms *A*′ and *E*′ (slopes) by the composite SES index

Education	AGE: 0–5	AGE: 6–10	AGE: 11–15	AGE: 16–20	AGE: 21–25
A	0.553	0.493	0.476	0.465	0.475
	0.021	*0.021*	*0.020*	*0.020*	*0.019*
A′	0.011	0.046	0.055	0.056	0.047
	0.005	*0.008*	*0.008*	*0.007*	*0.006*
E	0.498	0.467	0.453	0.445	0.440
	0.011	*0.009*	*0.009*	*0.009*	*0.009*
E′	0.143	0.141	0.138	0.132	0.119
	0.013	*0.014*	*0.014*	*0.013*	*0.013*
ISEI	**AGE: 0–5**	**AGE: 6–10**	**AGE: 11–15**	**AGE: 16–20**	**AGE: 21–25**
A	0.408	0.358	0.353	0.355	0.365
	0.021	*0.019*	*0.019*	*0.019*	*0.019*
A′	0.025	0.058	0.061	0.055	0.047
	0.006	*0.008*	*0.008*	*0.007*	*0.006*
E	0.594	0.570	0.561	0.554	0.549
	0.013	*0.011*	*0.011*	*0.011*	*0.011*
E′	0.085	0.082	0.071	0.072	0.071
	0.013	*0.013*	*0.013*	*0.013*	*0.012*
Income	**AGE: 0–5**	**AGE: 6–10**	**AGE: 11–15**	**AGE: 16–20**	**AGE: 21–25**
A	0.181	0.191	0.163	0.181	0.159
	0.017	*0.017*	*0.016*	*0.016*	*0.015*
A′	0.024	0.037	0.063	0.049	0.057
	0.004	*0.006*	*0.007*	*0.006*	*0.005*
E	0.830	0.725	0.691	0.667	0.658
	0.016	*0.013*	*0.013*	*0.013*	*0.013*
E′	0.276	0.259	0.196	0.203	0.180
	0.010	*0.011*	*0.011*	*0.011*	*0.011*

Note: Main effects for SES omitted.
Standard errors in italics.
N = 13,058.

For education and ISEI, we find that the interaction between the genetic component and parents' socioeconomic characteristics (*A*') is smallest during the earliest life stage (at age 0–5). The social stratification is stronger from age 6 onwards and does not substantially change later in life. For income, we find that stratification becomes stronger later, from age 10 onwards. The overall pattern was similar across all outcomes. Therefore, we do not find support for Hypothesis 2.

Interestingly, the interaction term *E*' is strongest during the earliest life stage and becomes weaker later. While this pattern holds across all outcomes, it is most pronounced for income. Thus, in broad terms, the two processes seem to be reciprocal: The stratification of genetic influences becomes stronger over the early life course, while stratification of the non-shared environment becomes weaker.

Finally, we considered *H3*. We expected that the genetic influences observed in the attainment taking place later in life mainly reflect the genetic influences associated with earlier outcomes. The results are shown in Table 2. In the unadjusted (baseline) models, the absolute genetic influences in ISEI range from 0.4 to 0.7 and in income from 0.3 to 0.5. These estimates are also reported in Figure 2 (bottom row). For ISEI, when we control for children's own education, genetic influences are reduced by 61% to 75% across SES groups. For income, the reduction in genetic influences is considerably lower, ranging from 13% to 24%. Controlling additionally for twins' ISEI as well reduces the genetic

Table 2. Variance components for *A* and *E* for twins' ISEI and income by parental socioeconomic status (quintiles of SES composite index)

Outcome	Parental SES	Baseline	Adjusted for child's education	Adjusted for child's education and ISEI	Baseline	Adjusted for child's education	Adjusted for child's education and ISEI	Explained by education		Explained by education and ISEI	
		A	*A*	*A*	*E*	*E*	*E*	*A*	*E*	*A*	*E*
ISEI	1 Q.	0.432	0.147		0.52	0.432		66%	17%		
		0.029	*0.015*		*0.022*	*0.017*					
	2 Q.	0.431	0.156		0.511	0.447		64%	13%		
		0.028	*0.017*		*0.021*	*0.018*					
	3 Q.	0.340	0.134		0.552	0.513		61%	7%		
		0.025	*0.014*		*0.022*	*0.019*					
	4 Q.	0.395	0.135		0.620	0.515		66%	17%		
		0.030	*0.014*		*0.025*	*0.019*					
	5 Q.	0.727	0.184		0.630	0.596		75%	5%		
		0.044	*0.022*		*0.026*	*0.024*					
Income	1 Q.	0.285	0.238	0.230	0.575	0.557	0.553	16%	3%	19%	4%
		0.025	*0.022*	*0.022*	*0.024*	*0.023*	*0.023*				
	2 Q.	0.230	0.200	0.197	0.460	0.445	0.432	13%	3%	14%	6%
		0.017	*0.016*	*0.015*	*0.018*	*0.017*	*0.017*				
	3 Q.	0.230	0.200	0.197	0.619	0.604	0.589	13%	2%	14%	5%
		0.017	*0.016*	*0.015*	*0.023*	*0.022*	*0.021*				
	4 Q.	0.264	0.229	0.228	0.789	0.742	0.731	13%	6%	14%	7%
		0.029	*0.027*	*0.027*	*0.032*	*0.03*	*0.029*				
	5 Q.	0.448	0.340	0.328	1.192	1.136	1.09	24%	5%	27%	9%
		0.046	*0.041*	*0.04*	*0.048*	*0.045*	*0.044*				

Note: Unadjusted baseline models, models adjusted for child education (for ISEI and income), and a model adjusted for education and ISEI (for income).
Standard errors in italics.
N (individuals) = 13,058.

component further, but the changes are minor. Thus, we only find clear support for Hypothesis 3 only in the case of ISEI. This suggests that the genetic influences that are important for education and ISEI are less important for income. This is also reflected in Figure 1, showing greater overall genetic influences for education and ISEI.

Controlling for the attainment taking place earlier also shows in differences between SES groups. In the case of ISEI, the initial differences in genetic influences between SES groups were no longer statistically significant after education was controlled for. Similarly, in the case of income, we find that the genetic influences found in the highest SES group are not statistically significantly different from the other subgroups after we control for education and ISEI. However, the genetic influences are rather small to begin with, and the differences between the socioeconomic groups are negligible. The differences between the groups in *E* are less affected by the addition of any controls in the case of both ISEI and income.

Discussion and Conclusions

In this article, we have presented our findings on the gene–environment interplay over the early life course in education, occupational standing, and income. In summary, our study highlights five findings. First, our baseline findings for education, occupational status, and income show that the relative importance of shared environmental influences was negligible. This challenges previous findings on the substantial influence of the shared environment on education (Branigan, McCallum and Freese, 2013). The results differ from those of earlier studies in Finland studying older cohorts but are similar to those in Norway involving more recent cohorts with similar institutional settings (Silventoinen *et al.*, 2004; Nisén *et al.*, 2013; Ørstavik *et al.*, 2014; Lyngstad, Ystrøm and Zambrana, 2017). For income, the result is in line with a previous Finnish study (Hyytinen *et al.*, 2019). There have been no previous studies on genetic influences in ISEI in Finland, and, to our knowledge, very few elsewhere.

Second, we find that genetic influences are strongest among the most advantaged families. This partly confirms our first hypothesis: There is no linear relationship between the strength of genetic influences and the quality of the family environment, and the differences between the other groups of families are small. Thus, the enhancement mechanism seems to work principally at the top end of the social spectrum. A similar pattern has been found in previous studies studying the social stratification of genetic influences using twin data (Baier and Lang, 2019).

Third, the social stratification of genetic influences is to some extent depending on the age at which parental SES is observed. In contrast to our expectations, parental social background measured early during childhood led to weaker interactions with genetic influences. This finding is an important addition to previous research on the role of socioeconomic rearing environment at different stages of the early life course. It suggests that the average contribution SES would be more or less constant across childhood and youth (Erola, Jalonen and Lehti, 2016). If gene-environment interactions were not taken into account, we would miss the life-course-specific pattern. It may be that parents have not reached their final level of socioeconomic attainment during children's early childhood, and once parents have achieved that, their status reflects more accurately their genetic potential. If this is the case, the differences we observe in the association between family background and genetic influences according to children's age can follow from gene–environment correlation related to parent's socioeconomic attainment. For future research, the results suggest that in order to fully account for stratification according to parental educational and socioeconomic characteristics in genetic influences, one should prefer indicators of parental SES that are observed later than during early childhood.

Fourth, in line with our third hypothesis, we found that the contribution of socioeconomic parental characteristics to genetic influences is stronger the earlier the maturity of an outcome is reached. More specifically, parental characteristics matter mostly for the genetic influences in education, and for occupational standing mostly because it is mediated by their children's education. Notably, in the case of income, stratification by parental characteristics was weak even before their children's own education was considered. This is striking: It suggests that nearly all of the factors behind parents' success or failure in terms of their observed socioeconomic outcomes cannot *on average* explain that much of how their children succeed economically by age 32–36.

Finally, the results showed the stronger importance of the non-shared environment among the children of parents of high SES. This result was consistent across the three outcomes as well as the indicators of parental SES, and aligned with previous studies showing that socioeconomic outcomes within families differ more strongly among advantaged children (Goldstein and Warren, 2000; Heflin and Pattillo, 2006). A possible explanation can be borrowed from research on stratified parenting (Lareau, 2011; Kalil, Ryan and Corey, 2012) showing that parents of higher social status make more child-specific investments based on their children's individual talents or particular weaknesses that can accentuate differences among their children (Baier, 2019). However, similar findings could also result from the multiplicative processes if advantaged parents or the children themselves prefer differential treatment. For example, the same innate talent in math could lead to different educational and career pathways and could encourage careers in either business or academia.

Our results also contribute to the broader discussion on equality of opportunity. As comparative research has shown that social background matters relatively little in Finland, this could lead one to expect that the genetic influences in attainment should also be particularly strong. To some extent, the results are in line with this: The shared environment alone matters very little compared to the results on older birth cohorts in Finland (Silventoinen *et al.*, 2004; Branigan, McCallum and Freese, 2013; Nisén *et al.*, 2013). However, there is an addition: the comparison of outcomes shows that a negligible impact of shared environmental influences does not mean that only the impact of genes would automatically become stronger; it can also change the differences due to the non-shared environment. To date, the role of non-shared environmental influences has barely been discussed in the literature on genetic influences in socioeconomic attainment (as a notable exception, see Beam and Turkheimer, 2013). These channels nonetheless appear to be relevant for intergenerational socioeconomic transmission processes.

A caveat regarding the data is that we could not follow income as long as would have been preferable (until over age 40); we only covered log mean income from at age 32–36. It may be that the stronger role of genes in the incomes of the highly educated parents we observe now reflects their children's improved chances to fulfil their own genetic potential, rather than the parents' investments for their children. If this is the case, the genetic influences on income would become even stronger later. Furthermore, the immediate family context is not the only environment that we are exposed to during childhood and youth. Extended families, schools, or neighbourhoods could have also contributed to the gene–environment interplay. Also a detailed analysis of gender differences was beyond the scope of our study.

Moreover, it may be that our method of estimating genetic influences by comparing same and different sex twins led to a bias in the results; for instance, previous twin studies on education in Finland have found a substantive effect of shared influences that we did not observe. Testing our hypotheses with increasingly available molecular genomic data could shed light on the mechanisms involved; for instance, in the context of the third hypothesis on mediation, direct measures for genetic influences relevant for education, occupation, and income would allow us to test directly to what extent the same genetic influences contribute to each outcome.

In sum, the results underline the value of studying the gene–environment interplay for a better understanding of intergenerational socioeconomic inequalities. Clearly, genetic inheritance plays a key role in this and should be more strongly integrated into stratification research. Importantly, the results show that our theoretical assumptions about the relationship between social inequalities, genes, and shared and non-shared environments are still relatively underdeveloped, especially regarding the importance and role of the non-shared environment. In the future, one of the key tasks of research on intergenerational social mobility and attainment should be the development of better theories on the relationship between gene–environment interplay and its implications for equality of opportunity. The latter goal calls for comparisons of results by applying similar research designs across multiple nations.

Supplementary Data

Supplementary data are available at *ESR* online.

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Notes

1 Shanahan and Hofer (2005) themselves noted that their typology was not exhaustive and has since been further developed by others, for example Belsky *et al.* (2009); Reiss, Leve and Neiderhiser (2013); and Boardman *et al.* (2014).

2 The data from administrative registers is considered as confidential. User permissions and remote access to the data can be applied from Statistics Finland, see http://www.stat.fi/tup/mikroaineistot/index_en.html (last accessed 6. July 2021). All codes for the replication of our results are provided in https://github.com/INVEST-flagship/Erola-et-al-2021-Socioeconomic-Background-and-Gene-Environment-Interplay-in-Social-Stratification (last accessed 6. July 2021).

3 The estimates of genetic assortative mating on education retrieved from molecular data could make the

method of Loehlin, Harden and Turkheimer (2009) obsolete. However, recent studies using the approach have not yet come to an agreement on the size of the estimate (Robinson *et al.*, 2017; Abdellaoui *et al.*, 2019; Barban *et al.*, 2019). Due to the ongoing debate and the lack of molecular information in our data, we prefer to follow the consensus method.

4 If a non-parametric specification was used, each model would have included five separate interaction terms, repeated by the age of the children when parental characteristics were observed.

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Conflict of Interest

There are no conflicts of interest.

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Jani Erola is a Professor of Sociology at the University of Turku and the director of the INVEST Research Flagship Center. His research interests include educational and socioeconomic attainment, family dynamics, socioeconomic inheritance, and social mobility. His publications on these topics have appeared in major social scientific journals such as *Demography*, *Social Forces*, *Social Science Research*, *European Sociological Review*, *British Journal of Sociology*, *Acta Sociologica*, and *Journal of European Social Policy*.

Hannu Lehti is a senior researcher at the University of Turku. Currently, he works at the INVEST Research Flagship Center. His research focuses on intergenerational social mobility, life

course disadvantages, social stratification, and evolutionary social science approach. His studies have been published for example in *European Sociological Review*, *Research in Social Stratification and Mobility*, and *Research on Finnish Society*.

Tina Baier is a Post-doctoral researcher at the University of Oslo. Her primary research interests include social inequality, education, family, and the integration of genetics in stratification research. Her work has been published in peer-reviewed journals such as *Journal of Marriage and Family*, *Sociological Science*, *European Sociological Review*, *Journal of Family Research*, and *Zeitschrift für Soziologie und Sozialpsychologie*.

Aleksi Karhula is a postdoctoral researcher at the Ecosystems and Environment Research Programme and HELSUS in the University of Helsinki, and at the Department of Social Research in the University of Turku. He has a wide range of research interests including different forms of intergenerational inequalities, segregation dynamics, and sequence analysis methodology. His work has been published in scientific journals such as *Demography*, *PLoS One*, *Advances in Life Course Research*, *Housing Studies*, and *Research in Social Stratification and Mobility*.