The role of mothers’ speech in the transmission of family background inequality

Anna Brown[1], Emily Wood[2], Jasmin Wertz[3] & Sophie von Stumm[4]

1. Faculty of Health, Sport and Behavioural Sciences, University of Northampton, Northampton, UK
2. Department of Child & Adolescent Psychiatry, King’s College London, UK
3. Department of Psychology, University of Edinburgh, Edinburgh, UK
4. Department of Education, University of York, UK

January 2026

Acknowledgements

We are grateful to the mothers and fathers, the twins, and the twins' teachers for their participation in the Environmental Risk (E-Risk) Study. We are also indebted to the E-Risk team for their dedication, hard work, and insights. E-Risk is funded by grants from the Medical Research Council (MRC) [G1002190, MR/X010791/1]. We thank Avshalom Caspi, Helen Fisher, and Terrie Moffitt from the E-Risk team for their feedback, guidance, and contribution throughout this project. Furthermore, we thank the members of our Advisory Board for their invaluable advice and comments on this research.

The Nuffield Foundation is an independent charitable trust with a mission to advance social well-being. It funds and undertakes rigorous research, encourages innovation and supports the use of sound evidence to inform social and economic policy, and improve people's lives. The Nuffield Foundation is the founder and co-funder of the Nuffield Council on Bioethics, the Ada Lovelace Institute and the Nuffield Family Justice Observatory. This project has been funded by the Nuffield Foundation, but the views expressed are those of the authors and not necessarily the Foundation. Find out more at: www.nuffieldfoundation.org. Bluesky: @nuffieldfoundation.org, LinkedIn: Nuffield Foundation.

Nuffield Foundation

Table of Contents

Table of Figures

Table of Boxes

Executive Summary

Introduction

Children from well-resourced families achieve, on average, higher school grades and gain more educational qualifications than those from under-resourced family backgrounds. The association between family background and children's education-related outcomes is likely driven by many factors. Here, we studied the role of one specific factor: The speech that children hear from their mothers.

Mothers' speech is part of a much wider constellation of influences. Yet, it has been pointed to as a likely driver of family background inequality in education. As a result, interventions that seek to increase children's educational success have targeted mothers' speech. To ascertain the potential long-term effectiveness of such interventions (i.e., the degree of change they will likely achieve), robust, longitudinal studies are needed that test associations between mothers' speech and children's education-related outcomes beyond the early years. This is the first study to report associations between mothers' speech and children's education-related outcomes during primary and secondary school. In addition, our research is the first to explore whether genetic confounding affects the association between mothers' speech and children's education-related outcomes. We leveraged data from a large, genetically sensitive, and UK-representative family cohort study that included 1,116 families with children born in the mid-90s who were assessed from age 5 through to 18 years.

Background

Children's early life language environments. Children differ considerably in their language development. The language environments that children grow up in are strong predictors of these differences in language development. Language environments are significantly shaped by caregivers' speech, in particular the speech that parents direct at their children and the speech that children overhear from their parents. Accordingly, previous studies observed significant associations between mothers' and children's quantity and quality of speech in early childhood.

The language gap. The language environments that children experience in early life vary systematically between families as a function of their socioeconomic status (SES). SES describes the economic and social resources that are available to families relative to the resources that other families have. In their seminal work, Hart and Risley (1995) concluded that there was a '30 million word' gap between the number of words that children from low SES backgrounds hear over a three-year period compared to children from high SES families. Mothers with greater socioeconomic resources tend to speak more often with their children, use more sophisticated vocabulary (i.e., rare words), and include a broader range of syntactic structures than mothers with fewer resources. Thus, SES-related variability in mothers' speech is thought to give rise to the 'word gap' during the early years that in turn leads to differences in children's language development. However, the notion of the 'word gap' has been criticised for deficit framing, as it risks portraying the language practices of lower SES families as inherently deficient rather than different.

Language ability in education. Language ability is a basic skill that underpins learning, including reasoning, cognition, and literacy, as well as of educational achievement itself (i.e., school performance). Children with greater language abilities at school entry are likely to outperform children with weaker language in learning progress and educational achievement, even when they are taught by the same teachers in the same classrooms on the same curriculum. These early performance differences can magnify across school years and education stages, like a snowball effect. An initially small difference in language ability builds on itself and can produce lasting inequities in education-related outcomes. It follows that SES-related disadvantages in language development likely forecast long-term differences in educational achievement and in the attainment of educational qualifications.

Research Questions

With studies presented in this report, we sought to overcome three limitations of previous research on the role of mothers' speech in the transmission of family background inequality in education. First, associations between mothers' speech and children's educational outcomes were not longitudinally studied beyond the early years – that is, not throughout the primary and secondary school years. Second, children's early life language environments were often only assessed in small samples that were not population-representative and afforded low statistical power. Third, associations between mothers' and children's language are genetically influenced, because mothers and their biological children share genes that affect language. Yet, previous studies in this area did not control for genetic confounding.

We capitalised on a large, genetically sensitive family cohort study called E-Risk (https://eriskstudy.com). The families in the cohort were identified with great care to represent the full range of socioeconomic conditions of England and Wales. From the full UK register of twin births, families were stratified and selected to mirror the UK population on key variables, including geographic region, urban versus rural residence, socioeconomic deprivation, and family structure (i.e., single-parent versus two-parent households). The representativeness of E-Risk of the wider UK population is reflected, for example, by E-Risk families' residential addresses that were matched to the United Kingdom's Index of Multiple Deprivation. The distribution showed that 25% of the families live in Britain's wealthiest and 25% in the poorest areas. E-Risk has maintained high representativeness since its inception, due to stratified sampling, oversampling of families from high-risk contexts, and exceptionally high retention (i.e., low attrition and loss due to longitudinal follow-up).

We addressed four principal research questions:

1. Does family background predict mothers' speech?
2. Does mothers' speech predict their children's education-related outcomes across school years?
3. Does mothers' speech mediate the association between family background and children's education-related outcomes?
4. To what extent is the role of mothers' speech in the transmission of family background inequality in education influenced by genetics?

Methods

E-Risk recruited 1,116 families with twins born between 1994 and 1996 across England and Wales. For 894 families, interview recordings were available of mothers' naturalistic speech, meaning that mothers spoke freely about their twins and their speech was recorded. These interviews were recorded by trained health researchers during visits to the families' homes when the twins were 5 years old. Interviews lasted at least 10 minutes, resulting cumulatively in 336 hours of recordings and an overall corpus of 2.5 million words of mothers' speech. From the interview transcripts, we extracted for each mother their vocabulary sophistication (% of rare words used in speech), lexical diversity (range of word types used in speech), and grammatical complexity (e.g., mean length of utterance). Between the twins' ages of 5 and 18 years, their learning skills – cognition and literacy – and their educational achievement were assessed using psychometric tests and teacher ratings. Learning skills refer to the basic capacities for processing information and acquiring knowledge, such as reading and writing, while educational achievement reflects the extent to which these capacities are realised within formal education. Family background was inferred from mothers' educational attainment, occupation and household income. Mothers' and children's genetic propensities for language and educational attainment were operationalised by polygenic scores that aggregate DNA variants.

Findings

Research Question 1. Does family background predict mothers' speech?

We found that mothers' education, occupation, and household income significantly predicted mothers' vocabulary sophistication, with small effect sizes. Small effects are meaningful: they are consistent and non-random, but far from large enough to be the primary determinants of mothers' vocabulary sophistication. Weaker and less consistent associations were observed between family background indicators and mothers' lexical diversity and grammar. The findings suggested mothers' SES is reflected in their vocabulary sophistication but not in other characteristics of mothers' speech. Thus, mothers' vocabulary sophistication may be a pathway in the transmission of family background inequality in education.

Research Question 2. Does mothers' speech predict their children's education-related outcomes across school years?

We investigated the long-term influence of mothers' speech on children's education-related outcomes. We found that the sophistication of mothers' vocabulary significantly predicted children's cognition, literacy, and educational achievement from age 5 through 18 years. Mothers' other speech characteristics – lexical diversity and grammatical complexity – were not significantly related to children's education-related outcomes. Our findings suggested that mothers' vocabulary sophistication plays a unique role in explaining children's differences in education-related outcomes. This result lends further support to the hypothesis that mothers' vocabulary sophistication is a distinct, meaningful pathway in the transmission of family background inequality in education.

Research Question 3. Does mothers' speech mediate the association between family background and children's education-related outcomes?

We tested whether mothers' vocabulary sophistication mediated the association between family background and children's education-related outcomes. We found this was the case: Mothers' vocabulary sophistication mediated the associations between family background (i.e., mothers' education and household income) and children's cognition and literacy. However, mothers' vocabulary sophistication did not mediate the association between family background and children's educational achievement (i.e., teacher ratings of school performance). These findings suggest for one that family background inequality that is transmitted through mothers' speech likely manifests in children's learning skills, like reasoning and reading abilities, rather than in educational achievement. For the other, they substantiate once more that mothers' vocabulary sophistication contributes to the transmission of family background inequality in education. That said, mothers' speech emerged as one meaningful factor among many, but not as a primary driver.

Research Question 4. To what extent is the role of mothers' speech in the transmission of family background inequality in education influenced by genetics?

We tested the influence of genetics on the associations between mothers' educational attainment, mothers' speech, and children's educational attainment. We used polygenic scores to capture mothers' and children's genetic propensities for speech and education-related outcomes. Polygenic scores, which aggregate DNA variants, offer a probabilistic estimate of a person's genotype to become expressed as a phenotypic trait, like educational achievement. That is, genetic propensities refer to a person's tendencies or preferences for certain behaviours that are associated with inherited DNA differences. We found that polygenic scores predicted mothers' educational attainment, mothers' speech, and children's educational attainment. This finding suggested that genetics influence the role of mothers' speech in the transmission of family background inequality in education. In further analyses, we partitioned the association between mothers' and children's educational attainment into pathways that likely reflect causal versus non-causal influences. Genetic confounding occurs when a putatively environmental factor, like mothers' speech, become associated with a developmental outcome, like children's education, because mothers' and children share genes, rather than because mothers' speech has an independent effect. Genetic confounding can mimic environmental causes but implies non-causal influences. Genetic nurture describes environmental influences on children's development that follow from their mothers' genetic propensities but are independent of children's genetic differences (i.e., DNA variants that mothers did not pass on to their children but that influence how mothers raise their children). Genetic nurture effects are interpreted as causal because they are environmentally mediated. Finally, we discerned nurture effects in our analyses that were independent of mothers' and children's genetic propensities. These nurture effects are thought to represent causal environmental influences. In our analyses, we found evidence for significant genetic confounding, genetic nurture, and nurture effects. These findings underscore the importance of discerning the gene-environment interplay when trying to understand how family background influences children's development. Furthermore, we found that mothers' vocabulary sophistication explained approximately 3% of the variance in family background inequality in education via genetic nurture and nurture, respectively. While these transmission effects are small, they likely reflect causal effects of mothers' vocabulary sophistication on the intergenerational transmission of educational attainment. We therefore conclude that mothers' vocabulary sophistication is an effective target for interventions that seek to improve children's education-related outcomes. That said, such interventions are likely to only achieve modest change, because of the small effect size: Mothers' vocabulary sophistication matters, but its influence is limited and only explains a small share of the differences observed. We also caution that further research is needed to assess whether mothers' vocabulary sophistication is modifiable before resources are invested in the development and implementation of related interventions.

Limitations

Our research has many strengths but must be interpreted with three key limitations in mind. First, we focused on mothers' adult-directed speech, including their vocabulary sophistication, lexical diversity, and grammatical complexity. Other aspects of mothers' speech and children's language environments were not assessed, including mothers' child-directed speech and the speech that children experience from other caregivers like fathers, peers, and teachers. Thus, our findings allow conclusions about only one of many language experiences that are potentially relevant for children's education-related outcomes. Second, identifying the causes that underpin associations between parenting and child development is difficult, because parents and children cannot be randomly allocated to each other, as true experiments require. Here, we analysed observational data from a well-powered, population-representative family cohort study that was genetically sensitive. While these data help strengthen causal inferences, causality cannot be proven. Third, our sample included families with twins, who may differ in their development from children of singleton births. To address this issue, we compared twins' and their younger siblings' (singleton births) language development from age 2 through 7 years, in a subsample of the Twins Development Study (TEDS). We found that twins were delayed in language development relative to their younger singleton siblings from age 2 through 4 years. However, by the age of 7 years, when children had started formal schooling, differences in language development between twins and their singleton siblings were no longer significant. Thus, we conclude that our findings about the role of mothers' speech for children's education-related outcomes based on analyses of a twin sample are generalisable to singleton birth children.

Conclusion

In a genetically sensitive, UK-population representative family cohort study, we found that an important characteristic of mothers' speech – vocabulary sophistication – likely exerts causal influences on children's education-related outcomes. Yet, corresponding effect sizes were small. By comparison, families' socioeconomic resources had more pervasive, long-term influence on children's education-related outcomes than did mothers' speech. Our findings suggest that any to-be-developed interventions that target mothers' vocabulary sophistication to improve children's education-related outcomes will likely produce modest change in these outcomes. Greater impact could be achieved if the socioeconomic inequalities were ameliorated that occur between the families that children are raised in.

Executive summary word count: 2,294 words.

Introduction

Inequality in the United Kingdom

Inequality in the United Kingdom (UK) takes many forms. Around a quarter of people at prime working age report having a long-standing illness, reflecting health inequality (Joyce & Xu, 2019). The birth of a child opens a gender wage gap between mothers and fathers that continues to widen for at least a decade, giving rise to gender inequality (Joyce & Xu, 2019). The UK's geographical inequality manifests as a matter of life and death: people living in the most affluent areas of the UK can be expected to live 8 to 10 years longer than those living in the most deprived areas (Joyce & Xu, 2019). Together, these examples illustrate the broad scope of inequality in the UK. In this study, we focus specifically on family background inequality in education, where differences in families' access to social and financial resources shape children's educational outcomes. For an explanation of key terms used when describing family background inequality, please see Box 1.

A key factor in families' access to social and financial resources is household income. The inequality of income distribution is high in the UK relative to other WEIRD countries (Western, Educated, Industrialised, Rich, and Democratic,
Joyce & Xu, 2019). To quantify this inequality, we can refer to the Gini coefficient that indexes the degree of inequality in the distribution of household incomes, whereby a larger percentage reflects greater inequality (Office for National Statistics, 2023). The Gini coefficient for the UK rose steeply in the 1980s and has remained high since then (Joyce & Xu, 2019). In 2022, the Gini coefficient for the UK was one of the highest in Europe at 37% (Office for National Statistics, 2023), behind Bulgaria at 38%, and ahead of Germany at 29% and France at 30% (Eurostat, 2024). These patterns highlight the extent to which economic resources are unevenly distributed across families in the UK. Disparities in household income can translate into differences between families' access to resources, such as healthy food (Pechey & Monsivais, 2016) and home learning tools (e.g., age-appropriate books and toys for children; Early et al., 2020). Additionally, they exacerbate existing inequalities, by increasing the prevalence of health and social problems including obesity, teenage births, and imprisonment (Pickett & Wilkinson, 2015; Wilkinson & Pickett, 2007).

The UK also has the highest intergenerational earnings elasticity in Europe, meaning that UK parents' income better predicts their children's income than do parents' incomes in other European countries (Corak, 2006). Strong associations between parents' income and their children's income are indicative of low intergenerational social mobility (i.e., no changes in social status across generations). Intergenerational mobility in the UK declined by almost 50% between 1958 and 1970 (Blanden & Gibbons, 2006) and has remained stably low since then (van der Erve et al., 2023). Figure 1 shows the relationship between family socioeconomic status and children's earnings at age 28 years, in a sample of English state-educated pupils who were born between 1986 to and 1988 (Carneiro et al., 2020; van der Erve et al., 2023). Sons from the most affluent families ranked on average 19 percentiles higher in earnings than sons from the most disadvantaged families, whilst daughters from affluent families ranked even 27 percentiles higher than those from under-resourced families (Carneiro et al., 2020; van der Erve et al., 2023). These findings show that, in the UK, transmission of family background inequality across generations is strong, with children's family background predicting their own financial status in adulthood.

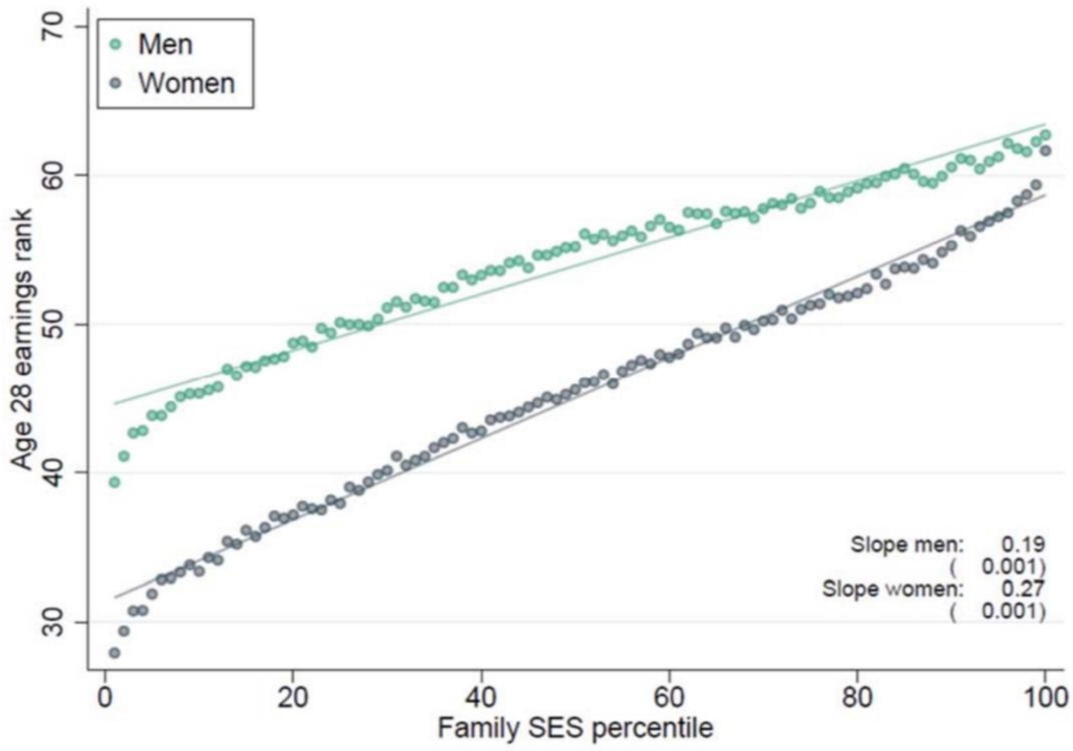

Figure 1: Income mobility at age 28 for people in England born in the years 1986-88 (van der Erve et al., 2023)

Note. Figure shows the relationship between family background and age 28 earnings rank by gender.

Much of the decline in intergenerational mobility in the UK between 1958 and 1970 has been attributed to the strengthening of the relationship between family income during childhood and children's later educational attainment (Blanden et al., 2007). It is in this context that the current project focused the role of mothers' speech as a key pathway in the transmission of family background inequality in education across generations. In other words, we examine how differences in everyday language use may help explain how socioeconomic inequalities are reproduced over time.

Box 1: The terminology of family background inequality

Throughout this report, we refer to differences in families' access to resources, which include wealth, education, and social class. At the highest and most abstract level, we use the term "family background inequality" to summarise that families differ vastly in the resources that they can afford their children and that inequalities follow from these differences.

We also use the term socioeconomic status (SES) to refer in a narrower sense to families' social and economic resources and position relative to that of other families. SES is often inferred from one's occupation (e.g., occupational prestige), education (i.e., highest educational qualification attained), and household income (Bradley & Corwyn, 2002). We also refer to families' resource availability, for example, by describing a family as "under-resourced," or having "limited access to resources." These terms are used to reflect the differences between families in their access to learning opportunities, educational support, and cultural engagements, as well as to material resources and many other factors. Using terms such as "low SES" or "under-resourced" defines families by what they do not have (i.e., deficit framing), rather than what they do have. Our intention is not to define families by deficits, but to highlight the challenges families might face as a consequence of their circumstances. By doing so, we hope to make constructive contributions to the conversations that aim to inform strategies for ameliorating the vast range of inequalities that UK families face.

Family background inequality

Differences in family background relate to life-course inequalities in health (Tubeuf & Jusot, 2011), well-being (Plenty & Mood, 2016), and education (Ermisch & Francesconi, 2001), whereby children from lower SES families experience on average less favourable outcomes. For example, children from lower SES families report more often adolescent smoking, physical inactivity, and poorer diet (Moore & Littlecott, 2015). They are also predicted to be two to three times more likely to develop mental health problems than children from higher SES backgrounds (e.g., Reiss, 2013). In education, children from lower SES families achieve on average lower school grades and obtain fewer GCSEs than those from higher SES backgrounds (Stopforth et al., 2021). Family background is likely to affect children's differences in life-course development through a vast number of pathways that contribute to the intergenerational transmission of socioeconomic disadvantage. Taken together, these findings show that family background shapes children's development across multiple domains, raising the question of which specific mechanisms drive these differences.

In this study, we focus specifically on education-related outcomes, which are pivotal for children's life-course development (e.g., Starr, Haider, et al., 2024). For example, school grades predict later earnings, whereby a one-grade increase in GCSE score is associated with an increase in lifetime earnings of £8,500, whilst one Standard Deviation[1] improvement in GCSE performance is associated with a lifetime earnings increase of approximately £96,000 (Hodge et al., 2021). In practical terms, this means that even relatively small differences in school performance can translate into substantial differences in life outcomes. Similarly, school grades at age 16 years predict later educational attainment, occupational prestige, financial attitudes, behaviour problems and wellbeing, with higher grades forecasting more favourable outcomes in adulthood (Starr, Haider, et al., 2024). The positive influence of school grades on life-course outcomes is stronger for children from lower SES families: Their school grades are even more predictive of their educational attainment, financial attitudes, and anxiety than those of children from higher SES families (Starr, Haider, et al., 2024). Understanding how these educational inequalities emerge and are transmitted across generations is therefore key. In particular, identifying modifiable processes—such as aspects of children's early environments—may help explain how family background shapes educational trajectories.

Family background inequality in education

One of the clearest ways in which family background inequality manifests is in children's educational outcomes. For example, children from lower SES households attain, on average, fewer educational qualifications and spend less time in formal education than children from higher SES households (Liu et al., 2022; Pensiero & Schoon, 2019). The degree of family background inequality in education can be inferred from the strength of the association between parents' SES and their children's educational attainment, such as whether they obtained GCSEs or A-levels, or their children's educational achievement, such as school or degree grades. Across samples from all around the world, the correlation

[1] 11.2 GCSE grades, across subjects.

between family SES and children's education, including measures of both attainment and achievement, is estimated to range from .22 to .28 (Liu et al., 2022). In practical terms, this means that family socioeconomic status is a strong and consistent predictor of how children perform in education, although it is not the only factor involved.

In Britain, family SES and children's performance in primary school have been shown to correlate at .28, an association that was remarkably stable across generations since the introduction of state-funded, compulsory education (von Stumm et al., 2022). Moreover, the attainment gap in Britain between children from higher and lower SES families widens from the first school years, when it is already evident, throughout secondary school (von Stumm, 2017). These findings align with reports on the disadvantage gap index by the UK government (Department for Work & Pensions, 2024). This index is used to quantify the difference in educational attainment between disadvantaged pupils (i.e., those eligible for free school meals, in local authority care, or adopted) and all other pupils in English state-funded schools. A disadvantage gap index score of 0 suggests no disadvantage, while a score of 10 implies maximum inequality in school performance (Department for Work & Pensions, 2024). For the past decade, the disadvantage gap index has hovered around 3, with only minor fluctuations (GOV.UK, 2023). The persistence of the disadvantage gap reflects the scale of the challenge for it to be closed. This, in turn, highlights the urgency to better understand the mechanisms that cause the disadvantage gap. In particular, identifying processes within children's everyday environments—such as their language experiences—may help explain how these inequalities emerge and persist.

In the current research, we focus on one such pathway: The speech that children are exposed to from their mothers. For details on our use of the term 'mothers' speech', please see Box 2.

Families' differential access to educational and financial resources is associated with differences in the children's early life language experiences (Hirsh-Pasek et al., 2015; Schwab & Lew-Williams, 2016). Indeed, policymakers and researchers have identified children's early life language experiences as a key pathway for the transmission of educational inequality (Greenwood et al., 2020). As a result, the language environments that children experience in their respective family homes have been targets of intervention efforts (e.g., Golinkoff et al., 2019). These efforts have often focused on mothers, who continue to serve as primary caregivers in most families and who are therefore thought to exert great influence on their children's language environment. Together, prior studies suggested that variation in children's language environments may be a key mechanism through which family background influences educational outcomes. This raises the question of which aspects of caregivers' speech matter most and how strongly they shape children's development.

Box 2: The terminology of mothers' speech

The term speech pertains to the vocalised sounds produced through articulation, fluency, and voice, according to clinical and technical guidelines. In contrast, the term language encompasses a broader system of communication, including comprehension, written forms, and non-verbal cues (Millard & Menzies, 2016). In policy and practice, the terms speech and language are often used interchangeably. In the research disciplines psychology, education, and linguistics, references to "speech delays" sometimes broadly imply language development issues (Malec et al., 2017; Quigley et al., 2024). In healthcare, "speech therapy" typically covers interventions targeting speech production and language comprehension. Public health campaigns frequently use "speech milestones" to describe general communication development, including speech and language (Ukrainetz & Fresquez, 2003).

For this report, we use the term speech when referring to our measures of mothers' vocabulary, lexicon, and grammar. This is to reflect the origin of our measures, which were derived from naturalistic speech samples, meaning that mothers spoke freely while their speech was recorded. Our terminology ensures that our measures are understood not to capture other components of language, such as comprehension, non-verbal communication, and written expression. We also wanted to avoid confusions with research on bilingualism or multi-lingual families, which can play a role – albeit one that was not studied here – for children's differences in developmental and education-related outcomes.

Mothers' speech

To examine this mechanism more closely, we focus on mothers' speech. Many people will act as caregivers to children during their early years. Yet, prior research on caregiving during children's early years has largely focused on mothers (e.g., Rowe et al., 2004). Mothers continue to serve as primary caregivers in many families, especially during the early years (Fry, 2023; Sullivan, 2021; Walthery & Chung, 2021). Thus, mothers' speech is the key driver of children's language environments when they are growing up (Hoff-Ginsberg, 1991; Pancsofar & Vernon-Feagans, 2006). Children's language environments are key for the development of various skills across domains, extending beyond children's own speech and communication (Nag et al., 2024; Pace et al., 2019). Because children's language abilities provide the scaffolding for developing a wide range of skills, interventions that seek to increase children’s educational success often target the home language environment, focusing on mothers’ speech (Adamson et al., 2020; Haring Biel et al., 2020). However, the extent to which such interventions can meaningfully improve children’s outcomes remains unclear. In the current research, we tested associations between mothers’ speech and children’s differences in cognition, literacy, and educational achievement after children started primary school. Our findings therefore provide an estimate of how much change interventions targeting mothers’ speech are likely to achieve.

In addition to mothers’ speech, we would have liked to include a measure of fathers’ speech in this study. Fathers are often overlooked in parenting research (Cabrera et al., 2018), despite fathers playing a significant role in children’s development, unique to the role of mothers (Jeynes, 2016; McWayne et al., 2013). Unfortunately, no data were available on the speech of fathers in our sample, so we were unable to include them in this research.

Mothers’ child-directed and adult-directed speech

Children’s language environments are diverse and dynamic, and mothers’ contributions to these environments change throughout children’s development. During infancy and into toddlerhood, the speech mothers direct at their children differs from the speech they use to address adults (Broesch, 2021; Jones et al., 2023). Mothers use shorter sentences (Furrow et al., 1979; Stern et al., 1983), simplified vocabulary (Cychosz et al., 2021; Fernald et al., 1989; Rowe, 2012), and more conversational, turn-evoking speech (e.g. wh-questions; Rowe et al., 2017) when speaking to children versus adults. These features of mothers’ speech are specific to child-directed speech. They are essential in aiding children in reaching the first development milestones in speech and language acquisition (e.g., acquiring words and constructing simple sentences; Matychuk, 2005; Montag, 2019). The importance of the unique features of child-directed speech for children’s language development decreases as children reach advanced language milestones. For example, in vocabulary development, child-directed speech aids children in acquiring their first words, which tend to be concrete object nouns (e.g., ‘cat’ and ‘dog’). Child-directed speech is less influential when children acquire more abstract nouns such as ‘guilt’ or ‘justice’ (Reggin et al., 2021). Similarly, for the development of grammar, child-directed speech aids children in producing their initial sentences, which are as simple as multi-word combinations (e.g., ‘I’m hungry’). Later on, when children construct increasingly complex sentences with a multi-clause structure (e.g., ‘I want to prepare food because I’m hungry’), associations with child-directed speech are weaker (Balthazar & Scott, 2024).

As children mature, mothers' child-directed speech increasingly resembles the speech that mothers also direct at adults: Mothers address one-year-old infants with speech that is distinct from the speech they direct at five-year-olds (Glas et al., 2018; Rowe, 2012) – an age by which the differences between child- and adult-directed speech start to blur (Liu et al., 2009). Adult-directed speech better reflects than child-directed speech the speech that children are exposed to during the years of formal schooling from the age of 5 years onwards. This alignment suggests that adult-directed speech may be particularly relevant for policy and educational interventions, as it more closely resembles the language demands children encounter in classroom settings and academic learning. In line with this logic, we hypothesised that mothers' adult-directed speech would predict children's development in domains that are nurtured through dialogue and other forms of language-based exchanges, such as school performance (van der Veen & van Oers, 2017) and literacy skills (Duff et al., 2015). No previous study tested the predictions of mothers' adult-directed speech for children's long-term education-related outcomes. Our research here addressed this gap: We extracted mothers' lexical diversity, vocabulary sophistication, and grammatical complexity from transcripts of their adult-directed speech when their children were 5 years old, and we then tested whether these adult-directed speech characteristics predicted children's cognitive, literacy, and educational achievement from ages 5 to 18 years.

The relationship between mothers' and children's speech

The characteristics of mothers' speech are associated with their children's language development. A recent meta-analysis confirmed that the quantity and quality of mothers' speech predicted their children's expressive and receptive vocabulary across 52 studies that contained data from over 2,700 families (Anderson et al., 2021). These findings suggest that speaking more with your children through developmentally enriching communications aids children in grasping and utilising a wider variety of vocabulary (Anderson et al., 2021).

The role of the quantity and quality of mothers' speech for children's language development is dynamic and evolves over time. The quantity of speech helps to initiate the language learning process, but the quality of speech becomes more important once children have developed the basic skills for processing speech (Golinkoff et al., 2019; Rowe, 2012). The quality of mothers' speech, typically indexed by measures of lexical diversity and vocabulary sophistication, is key for advancing children's language development beyond the early years and helps children master the challenges of primary and secondary education (Jones et al., 2023; Rowe, 2012).

Vocabulary is an important characteristic of mothers' speech. The diversity and rarity (i.e., sophistication) of mothers' vocabulary correlate positively with the diversity of their children's vocabulary (d'Apice et al., 2019; Rowe, 2012; Rowe & Snow, 2020). A similar picture has emerged for grammar: The grammar of mothers' speech predicts the grammatical structure of children's spoken sentences (e.g., the use of multiple clauses; Huttenlocher et al., 2002). Therefore, the more complex sentences that mothers use, the more complex their children's sentences will be (Huttenlocher et al., 2010). Although previous studies tended to interpret associations between mothers' and children's speech in terms of causal environmental transmission effects, mothers' speech is likely only one meaningful factor among many.

Box 3: Assessing mothers' quality of speech

For the current project, we assessed mothers' quality, not the quantity of speech. We focused on mothers' (a) lexicon, which included lexical diversity and vocabulary sophistication, and (b) grammatical complexity.

(a) Lexicon. The lexicon captures the diversity and sophistication of mothers' vocabulary. Lexical diversity reflects the variety of words a person uses: High diversity suggests that the speaker uses a wide range of different words with minimal repetition of the same words. For example, 'The teacher taught the students, and the students listened to the teacher' would reflect comparatively low lexical diversity, while the sentence 'The teacher engaged the students, who paid close attention to her lesson' shows higher lexical diversity as different words are used, and fewer words are repeated.

Vocabulary sophistication indexes the complexity and rarity of words in speech. On average, people's vocabulary comprises about 27,000 words (Brysbaert et al., 2016). Yet, most everyday speech relies on common words that are learnt early in development (e.g., basic nouns like 'house' and 'food' and verbs like 'have' and 'walk'; Weizman & Snow, 2001). The Dale-Chall Word List (Chall & Dale, 1995) is a collection of 3,000 words identified as common, in the way that they are easily used and understood by most 4th-grade U.S. students (approximately 9-10 years old). Because vocabulary sophistication involves using words that are not common, the Dale-Chall list can help identify sophisticated vocabulary within speech: Those words that are not contained in the Dale-Chall Word List.

(b) Grammar. Grammar refers to the rules that govern how we structure words and construct sentences to communicate meaning. Grammar in speech can be measured on a continuum from simple single-clause sentences (e.g., 'I eat an apple') to multiple-clause sentences with increasingly complex grammatical structures (e.g., 'I haven't had time to eat lunch, so I need to eat an apple'; Nippold et al., 2014). The complexity of these structures can be quantified, for example through the *number of verbs that are used per utterance, proportion of complex clauses,* and *mean length of utterance* (MLU). MLU is calculated by averaging the number of morphemes per utterance (the smallest units of meaning, such as "eat" or the plural "-s"). A higher number of verbs per utterance, higher proportion of complex clauses and higher MLUs tend to indicate greater grammatical complexity in speech, such as embedded clauses and varied sentence types.

For this project, we capitalised on qualitative, adult-directed interviews that were collected from a population-representative cohort study of families. Mothers' lexical diversity, vocabulary sophistication, and grammatical complexity were extracted from the transcripts these interviews (see Box 3 for details on the assessment of mothers' quality of speech). Lexical diversity captures the range of different words mothers use in their speech, while vocabulary sophistication indexes how many rare words mothers use (Rowe, 2008; Weizman & Snow, 2001). Grammatical complexity was inferred from the complexity of mothers' speech at the sentence level (e.g., by calculating the number of verbs and clauses used per utterance as well as the average length of each utterance), with higher scores reflecting greater grammatical complexity.

Mothers' socioeconomic status and their speech

In social science research, SES is often inferred from educational attainment, household income, and occupation (e.g., Bradley & Corwyn, 2002; Duncan & Magnuson, 2012). Research has consistently shown that children from higher SES families have advantages in educational achievement (von Stumm, Cave, et al., 2022) and attainment (Stopforth et al., 2021), as well as many other areas (see also above). SES indexes the resources available to families (see Box 1 above), including access to educational resources and learning opportunities that shape children's developmental environments.

Based on their seminal research, Hart and Risley (1995, 2003) coined the term of the '30-million-word gap' between children from lower and higher SES family backgrounds during their early years. This work highlighted early language exposure as a potential mechanism linking socioeconomic background to later developmental outcomes. Later research into the SES-related differences in mothers' speech confirmed that the quantity and the quality of mothers' speech varies as a function of their SES (Hirsh-Pasek et al., 2015; Hoff, 2003; Rowe, 2008). On average, mothers described as high SES tend to use more complex and diverse vocabulary and sentences than those identified as mid to low SES (d'Apice et al., 2019; Hoff, 2003; Huttenlocher et al., 2010; Rowe, 2012). Together, these findings suggest that children's early language environments systematically differ as a function of family background.

The SES-related differences in mothers' speech mean that children's early life language experiences are conditioned by their family background (Hoff, 2013). This disparity in children's language experiences may then become reflected in children's language development, with children from lower SES households lagging behind in their same-aged peers from higher SES households (Clegg & Ginsborg, 2006; Fernald & Weisleder, 2015). In one study, for example, children from low-income families knew 30% fewer words than children whose parents were part of a middle-income group (Frank et al., 2021). Based on these and other findings, a model for the transmission of family background inequality in education emerged, which is illustrated in Figure 2. In essence, this model positions mothers' speech as a key link between socioeconomic conditions and children's developmental outcomes (cf. Pace et al., 2017; Rowe, 2018).

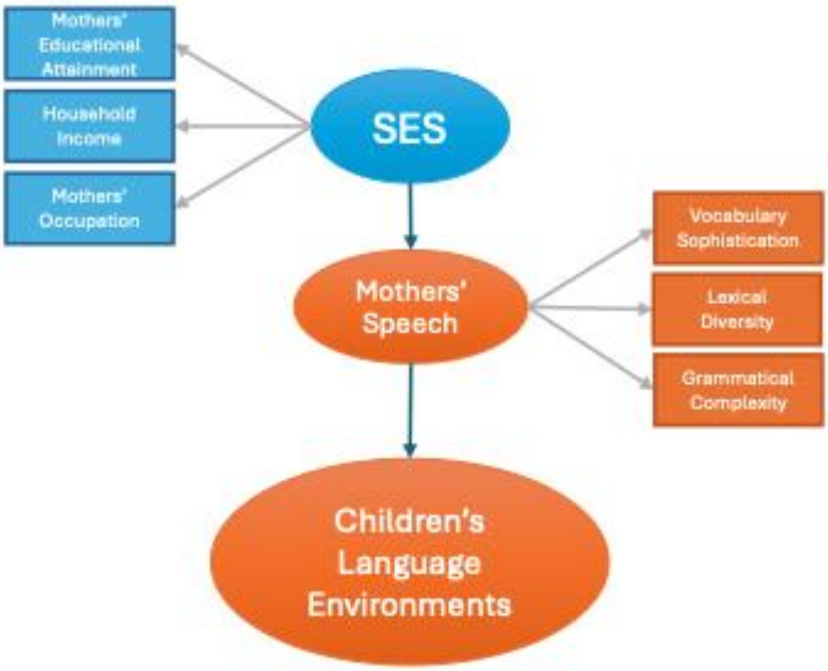

Figure 2: Pathway from mothers' socioeconomic status (SES) to children's early language environments

Note: This model reflects the hypothesis that mothers' SES, inferred from education, occupation, and household income, influences their speech, including lexical diversity, vocabulary sophistication, and grammatical complexity, that in turn shapes children's language environments.

The mechanisms that drive the associations between SES indicators and mothers' speech are poorly evidenced to date. Many hypotheses suggested that mothers' educational qualifications should have the most robust relations with their speech (Hartas, 2011), for example, because spending more time in formal education helps with developing lexical diversity, vocabulary sophistication, and grammatical complexity (Hoff, 2003; Hoff-Ginsberg, 1998). The reverse direction of influence is equally plausible: Having greater lexical diversity, vocabulary sophistication, and grammatical complexity may facilitate engaging in formal education for longer. Inferring the direction of causality from observational data for complex associations like this is difficult (Starr, Oginni, et al., 2024) and thus, we can only speculate about the origin of associations between mothers' education and their speech. As a result, while associations between SES and mothers' speech are well established, the direction and underlying mechanisms of these relationships remain uncertain.

The pathways through which household income and occupation influence mothers' speech are even less well understood. Lower household income levels can increase cognitive load and stress, both of which have been associated with mothers talking less to their infants (Ellwood-Lowe et al., 2022; Roby & Scott, 2022). However, the mechanisms by which income and occupation affect the quality of mothers' speech have not yet been directly tested. Likewise, how strongly SES indicators predict mothers' speech relative to each other (e.g., education versus income) has not been systematically compared. Therefore, it remains unclear whether associations between mothers' speech and their socioeconomic background vary across SES indicators, and if and in what ways such variations may be meaningful.

Mothers' speech and family background inequality

To examine this pathway more closely, Figure 3 illustrates how mothers' speech may serve as a pathway in the transmission of family background inequality in education. We propose two complementary explanations for how mothers' speech may influence children's outcomes. The two hypotheses as to why mothers' speech may predict children's education-related outcomes are (a) differences in abilities (i.e., in learning skills) and (b) in the familiarity with linguistic codes that prevail in formal education settings. Accordingly, we differentiated children's education-related outcomes into two categories, including learning skills on the one and educational achievement on the other hand. We use the term learning skills to describe children's basic capacities for processing information and acquiring knowledge, such as cognition and literacy. By comparison, the term educational achievement refers to the extent to which these capacities are realised within formal education. This distinction allows us to differentiate between underlying capacities for learning and their expression in formal educational settings.

(a) *Differences in ability.* Children's differences in language ability at school entry predict their learning skills that in turn underpin their educational achievement (Pace et al., 2019). Here, we focused on two crucial learning skills: cognition and literacy (Marchman & Fernald, 2008; Perszyk & Waxman, 2018). Cognition is the developmental domain involving mental processes like memory, problem-solving, language and reasoning that enable children to understand and interact with the world. Literacy is the domain focused on the ability to read, write, and interpret written language. The exposure to high-quality speech benefits verbal and non-verbal cognition because it helps categorise thoughts, improving memory, and enhancing executive function (Perszyk & Waxman, 2018). Exposure to high-quality speech also advances phoneme segmentation, which refers to the ability to recognise and separate the sounds of speech. The ability to recognise the individual sounds that form the words used in speech aids language development, as well as learning to read and acquiring literacy (Dickinson et al., 2010; Dickinson & Porche, 2011). In sum, the 'differences in abilities' hypothesis proposes that children's differences in exposure to speech during the early years manifest in differences in children's cognition and literacy skills. These skills are key to doing well in education and have far-reaching influence on all achievement- and performance-related outcomes, because they are basic abilities. In short, this account emphasises that early language exposure shapes foundational skills that support later learning and performance.

(b) *Familiarity with linguistic codes.* By contrast, an alternative hypothesis to the 'differences in abilities' model is that SES differences in speech environments account for differences in children's familiarity with the linguistic codes that prevail in formal education settings (Baugh, 2017; Bernstein, 1971; Cushing, 2021; Dudley-Marling & Lucas, 2009). Related linguistic codes also feature in other achievement and performance contexts, like in the workplace (Roberts, 2010). Children raised with fewer opportunities to learn these linguistic codes or styles may – unwittingly – communicate in language patterns that lead to stereotyping, ridicule, discrimination, and exclusion (Kircher & Fox, 2021; Spencer et al., 2013). As a result, small achievement gaps that are observable during the early school years may persist and deepen throughout education because of children's ways of speaking (Lippi-Green, 2011). The 'familiarity with linguistic codes' hypothesis implies that educational disadvantages due to early life speech environments can be attributed to differences in speech mannerisms (cf. 'habitus'), and perhaps more so than to differences in children's cognition and literacy skills (i.e., 'differences in abilities' model). This perspective highlights how social norms around language use may influence educational success independently of underlying cognitive abilities.

The two hypotheses (a and b) are not mutually exclusive: Accepting one does not imply rejecting the other, and both are likely to contribute to explaining the link between children's speech environments and their later education outcomes. Instead, they likely capture different but complementary pathways through which early language environments shape educational outcomes. However, it is also plausible that each hypothesis plays a distinct role for children's education-related outcomes, when these are differentiated into learning skills and educational achievement (see Figure 3). That is, the 'differences in ability' model is likely to account better for the association between children's language environments and their learning skills than the 'familiarity with linguistic codes' hypothesis. Conversely, the latter hypothesis pertains more to children's differences in educational achievement than their differences in learning skills.

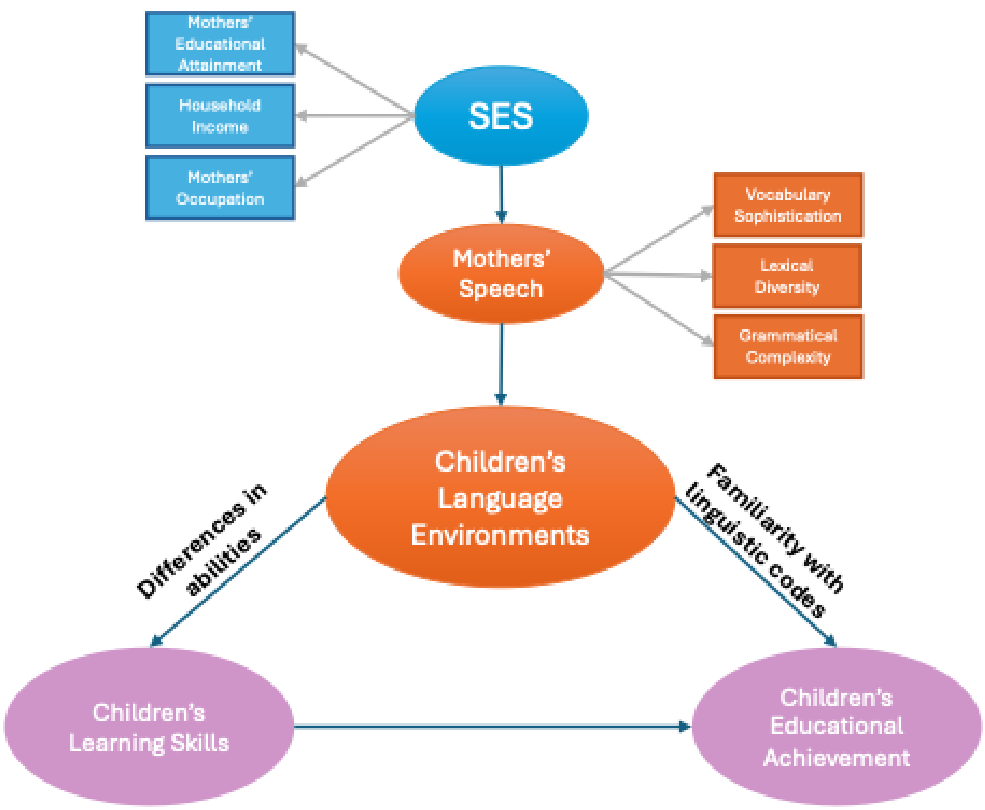

Figure 3: Pathway from mothers' socioeconomic status (SES) to children's education-related outcomes

Note: This model extends Figure 2 to illustrate how influence on children's education-related outcomes passes through mothers' SES and speech and children's language environments via the 'differences in abilities' model and the 'familiarity with linguistic codes' hypothesis.

Children who start primary school with advanced language skills often continue to improve relative to their peers in educational achievement and attainment that in turn lead to positive life outcomes (Johnson, Beitchman, & Brownlie, 2010; Snow & Powell, 2012). This phenomenon is likely due to children's differences in both their abilities and in their familiarity in linguistic codes that are prevalent in formal education settings.

Disentangling the gene-environment interplay

Prior research on the role of mothers' speech in the transmission of family background inequality in education often adopted a so-called 'environmentalist' perspective. Environmentalist perspectives on child development assume that children are akin to 'empty vessels' that can be filled up with environmental experiences. Depending on how enriching and beneficial these environmental experiences are, children will develop differently. Applied to the context of our project, mothers' speech may be understood as an environmental input factor that children experience. This experience, in turn, affects children's language development, as well as their cognition, literacy, and educational achievement (Furrow et al., 1979). This perspective offers promise and scope for interventions that aim to improve children's language and education-related outcomes. For example, aspects of mothers' speech – such as lexical diversity – that benefit children's language learning and that are modifiable could be targeted by interventions to improve children's language development. We refer to this as the classic model of transmission, where mothers create environments that influence their children's outcomes and that can be effectively changed (i.e., these environments are modifiable). In essence, this model assumes that differences in children's outcomes are primarily driven by differences in their environments.

However, this perspective does not fully account for the role of genetics. In most studies of relations between the environments that parents expose their children to and children's developmental differences, mothers and children are genetically related. It follows that within-family associations between mothers' speech and children's language might not just due to environmental effects but can also stem from shared genetic influences. In other words, when a mother and her child use sophisticated vocabulary in their speech, this resemblance is partly due to their shared language-related genes, not just how the mother speaks to the child. Here, children's differences in the environmental experience of mothers' speech would be a 'by-product' of genetics rather than the true cause for the association between mothers' speech and children's language development. This type of 'by-product' is known as **genetic confounding**, where genetic influences account for some or all the association between a putatively environmental factor and children's developmental outcomes. In other words, what appears to be an environmental effect may partly reflect shared genetic influences between parents and children. A full definition of genetic confounding, as well as definitions of all genetic terms use in this report, which when first used are marked in bold below, can be found in the glossary (p.78-80).

Genetic confounding does not invalidate the classic model of transmission per se, but it helps disentangle genetic and environmental pathways of transmission (see Figure 4). Disentangling true environmental causes from genetic confounding is key to estimating the extent to which interventions may be effective: If associations between environment and outcome are largely due to genetic confounding, big changes to the environment will achieve little change in the outcome. One of our current project's aims was to disentangle the genetic from the environmental influences on the role of mothers' speech in the transmission of family background inequality in education. This distinction is crucial because it determines how much change we can realistically expect from interventions targeting the environment.

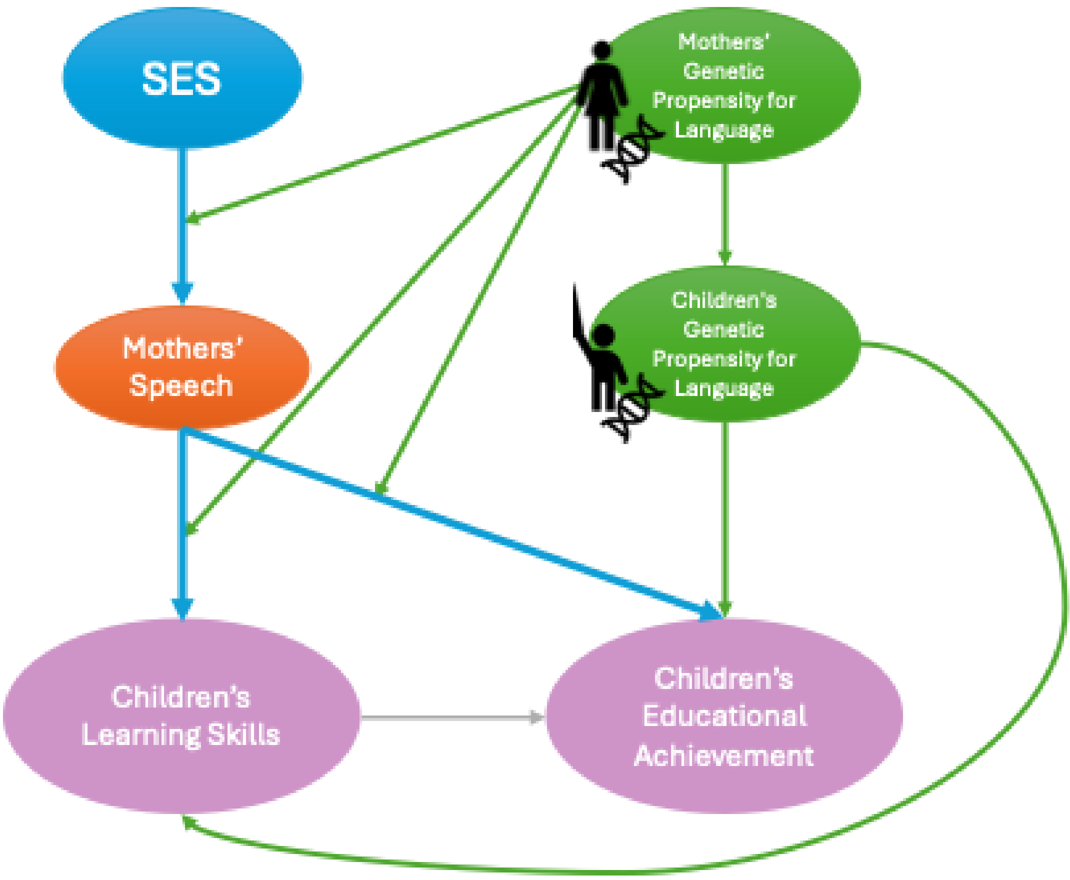

Figure 4: The role of genetic influences on children's education-related outcomes

Note: Paths shown in green illustrate genetic influences, while blue paths index putatively environmental effects. Paths from mothers' genetic propensity (i.e., the tendency to behave in certain ways because of inherited DNA differences) for language onto environmental effects index genetic confounding. Paths from children's genetic propensity for language to education-related outcomes reflect genetic influences on children's learning skills and educational achievement.

Finding genetic influences: A brief note on heritability

To explore the role of genetics in the classic transmission model, we need to consider to what extent the differences between traits and behaviours (e.g., language and educational achievement) are heritable. To address this issue, it is necessary to understand how genetic influences are quantified. This section briefly outlines what heritability is and how it is inferred in traditional twin study and adoption study designs, as well as via recent molecular genetic methods that were applied in the current research. The section below also addresses common misconceptions about heritability, emphasising the importance of nuanced interpretations of findings on the gene-environment interplay.

The statistic of heritability

Heritability is a statistical estimate that describes the proportion of the differences (or variation) observed between people in a trait or behaviour that can be attributed to their genetic differences. Heritability has traditionally been inferred from **twin and adoption studies**, which compare the resemblance in behaviours among relatives of different degrees of genetic relatedness. For example, monozygotic twins, also referred to as identical twins, are genetically identical and share 100% of their inherited DNA differences. In contrast, dizygotic twins share only 50% of their segregating genes, similar to other fraternal siblings that were born to the same biological parents in independent pregnancies. Comparisons of the resemblance in a trait between monozygotic and dizygotic twins allows drawing inferences about the heritability of traits. If genetically identical twins show greater similarity in a trait or behaviour compared to non-identical twins, differences in the trait must be, at least partly due, to differences in genetics (i.e., differences in the trait are heritable to some degree). Importantly, heritability does not indicate how "genetic" an individual is, but rather how much genetic differences contribute to variation within a population. A vast body of empirical research using twin and adoption designs has shown that virtually all human traits and behaviours are heritable, and on average quite substantially so (Polderman et al., 2015). Accordingly, children's differences in cognition (Haworth et al., 2010), language (Stromswold, 2001), and educational achievement (De Zeeuw et al., 2015) are also heritable.

It is important to note that twin and adoption studies do not directly measure genetic variation (i.e., DNA) at the individual level but rely on latent estimates of genetic influences by comparing variances across different groups (i.e., relatives of different degrees of genetic relatedness). More recently, research has begun to use molecular-genetic methods to study genetic influences on individual differences. The findings from these molecular-genetic studies generally corroborated those from twin and adoption studies that traits and behaviours are heritable, although they achieve on average lower estimates of heritability (see Plomin & von Stumm, 2018 for details on discrepancies in heritability estimates across methods). Together, these approaches provide converging evidence that genetic influences are widespread across human traits.

(Mis)interpreting findings of genetic influences

Despite their importance, heritability estimates are often misunderstood. Four common misinterpretations are outlined below.

The first is that heritability refers to individuals rather than populations. For example, a heritability estimate of 40% is misinterpreted to mean that 40% of an individual's behaviours are influenced by genetics, and the rest (i.e., 60% of the person's behaviour) is due to their environment. Yet, the correct interpretation of heritability is that 40% of the *differences between individuals* in a population can be attributed to the genetic differences between them.

A second common misinterpretation is that heritability is fixed and does not vary across time, age, or other characteristics of the population being studied. However, estimates of heritability can vary and do quite considerably so. For example, heritability estimates for cognitive ability range from approximately 40% in childhood to 60-70% in adolescence and adulthood (Haworth et al., 2010). Equally, finding high heritability does not mean that people's differences are immutable. Height serves as an example: About 80% of people's differences in height are heritable (Visscher, 2008), meaning that the vast majority of differences in people's height is due to their genetic differences. Yet, the average height of people has increased substantially since the beginning of the 20th century (NCD Risk Factor Collaboration (NCD-RisC), 2016). An extreme example comes from South Korea, where the average height increased by 18cm over the course of a hundred years from 1896 to 1996. This compares to an increase of 8cm in average height globally over the same time period (NCD Risk Factor Collaboration (NCD-RisC), 2016). Changes to the gene pool cannot explain such dramatic, population-wide gains in height over 100 years because evolutionary processes tend to occur at a much slower pace.

A third common misinterpretation is that heritability is caused by a single gene (e.g., 'the gene for intelligence'). However, genetic research has shown that people's differences in traits and behaviours are 'polygenic'. That is, trait and behaviour differences are influenced by thousands of genetic variants (i.e., polygenic) that are spread across the **genome** (i.e., a person's entire set of genetic variants) rather than any one single genetic variant (cf. monogenic). Each of these thousands of genetic variants likely only shares a minuscule association with people's differences in a trait or behaviour, but collectively they can index genetic risk or resilience for an outcome.

Finally, there is the misconception that genetic and environmental influences are entirely independent and even oppose one another (as exemplified in the expression "nature versus nurture"). Yet, genetic and environmental influences are intertwined by a complex interplay, meaning that they correlate and interact with each other. Taken together, these points highlight that genetic influences are probabilistic, context-dependent, and intertwined with environmental factors.

Causal inferences in genetically sensitive studies

These complexities have important implications for causal inference in studies of parenting and child development. The finding that genes and environments do not operate independently of one another complicates the interpretation of genetic influences. It also complicates the interpretation of influences typically considered environmental, such as parenting. That is, if a study observes an association between an aspect of parenting, for example how often parents read to their child, and a child outcome, such as children's own reading abilities, this association could be due to confounding by genetic influences. Genetic confounding could occur if parents' genes are associated with their parenting and are also passed on to their children in whom they influence traits or behaviours (Wertz et al., 2019). An alternative pathway of genetic confounding could also occur if children's genes influence both the parenting they receive and their traits or behaviour. In both scenarios, associations between parenting and children's outcomes may not reflect a **causal** effect of parenting on children (i.e., what is typically thought of as 'nurture'). Instead, parenting may merely be a marker of parents' or children's genetic predispositions (Knafo & Jaffee, 2013; Moffitt, 2005). As a result, observed associations between parenting and child outcomes do not necessarily imply that parenting causally shapes those outcomes.

To rule out genetic confounding, genetic influences need to be controlled for. One approach to do this, which we used in the current project, is to measure the **genetic propensities** of parents and children, and control for them when testing associations between parenting and children's outcomes. Genetic propensities can be indexed by '**polygenic scores**' that are aggregates that capture the effects of thousands of DNA variants across a person's genome on a person's traits or behaviours. In simple terms, polygenic scores summarise an individual's genetic propensity for a given trait based on many small genetic effects. Polygenic scores can be constructed based on the results of **genome-wide association studies (GWAS)**, which test links between genetic variants and traits and behaviours (for more detail, see Box 4). For example, a GWAS of educational attainment in over a million people identified genetic variants associated with how much education a person completes (Lee et al., 2018). Each of these variants alone explained very little difference in educational attainment, but together, combined in a polygenic score, they explain approximately 16% of people's differences in educational attainment (Wilding et al., 2024). This means that genetic differences account for a meaningful, but not complete, portion of variation in educational attainment. This phenomenon is known as polygenicity, where many DNA variants are associated with one target trait (here educational attainment). The effect size of polygenic scores in predicting educational attainment is considerable. By comparison, school quality ratings (i.e., Ofsted) explain less than 1% variance in end-of-compulsory school grades after accounting for prior school performance and family background (von Stumm et al., 2020). This comparison illustrates that genetic influences can be substantial, although they operate alongside many environmental factors.

Box 4: Constructing polygenic scores

A person's genome is their complete set of genetic information, made up of a unique sequence of DNA pairs written with four letters (A, T, C, and G). Genome-wide association Studies (GWAS) test associations between genetic variants that differ between people and people's differences in a phenotypic target trait, such as educational attainment. The genetic variants that differ between people are called single-nucleotide polymorphisms (SNPs). They are the smallest unit of genetic differences between people (i.e., single = at one locus only; poly = many; morphism = forms). SNPs are like tiny "spelling differences" in the genetic code that occur between people. Only about 0.2% of the human genome features such spelling differences, meaning that there are about 3-4 million SNPs that differ between across the genomes of two individuals. The remainder of our genomes' 3.2 billion base-pairs is the same between people. The summary statistics from GWAS index which SNPs are associated with a phenotypic target trait, and how strong these associations are. Information from the summary statistics can then be used to score genotype data that is available in a sample of individuals. That is, for each individual in the sample, SNPs associated with the target phenotype are weighted by their estimated strength of association and added to build a polygenic score that reflects an individual person's genetic propensity for the phenotypic target trait. Thus, polygenic scores are aggregates of individual DNA variants that differ between people, indexing the probability of a person to express a phenotypic trait.

If polygenic scores are available for parents and children, these can be used to control for genetic confounding in analyses of associations between parenting and child outcomes. This approach is similar controlling for confounding by other variables (e.g., age, sex, SES) in analyses of observational data. Genetic confounding is indexed by the extent to which associations between parenting and child outcomes are reduced after including parents' and children's polygenic scores. Equally, nurture effects can be inferred from the extent that the association between parenting and child outcomes *remain* when including parents' and children's polygenic scores. Nurture refers to parenting influences on children's traits and behaviours that are independent of genetic confounding. Figure 4 above illustrates how genetic confounding can occur.

Associations between genes and environment do not always lead to genetic confounding. Another possibility is that genetically influenced parenting still affects children's educational attainment. For example, even if parents' genetics influence how often they read to their child, the reading frequency may affect children's educational achievement, over and above children's own genetic propensities. This possibility has been referred to as 'genetic nurture', or alternatively 'nature via nurture,' because it is an effect of parents' genes that is mediated by phenotypic parenting. Recent research provides some evidence that parents' genetic propensities for educational attainment influence children's educational success, even if these genes are not passed on from parent to child (cf. Starr et al., 2025). Again, this possibility can be tested using polygenic scores. If parents' polygenic scores predict children's outcomes, such as educational achievement, even after controlling for children's own polygenic scores, this would suggest genetic nurture. It is then possible to test whether there are any environmental variables that mediate this effect, including, for example, parenting behaviours like joint book reading (Wertz et al., 2020). Using this approach makes it possible to test how nature and nurture combine to influence children's development.

Polygenic scores: A brief introduction

The early 2000s saw the decoding of the human genome (International Human Genome Sequencing Consortium, 2001) and the mapping of the genomic variation in human populations. Decoding the human genome means identifying and understanding the complete set of DNA instructions that make up who we are, similar to translating a massive book written in a unique language made of only four "letters" (A, T, C, and G). By "reading" this genetic code, scientists can learn about what makes us unique and map the variation of this code in human populations (Gibbs et al., 2003)

The decoding of the human genome has made it possible to identify the DNA variants that drive the heritability of **phenotypic** trait differences. These DNA variants, known as **single-nucleotide polymorphisms (SNPs)**, mark the smallest unit of genetic differences between people (see also Box 4). For instance, in the 'book' of our genome, this would be the difference between having an 'A' or a 'C' as the first letter on a page. The SNPs that drive the heritability of a phenotypic trait can be identified in so-called genome-wide association studies (GWAS). GWAS test associations between people's SNPs and their differences in a target phenotypic trait. GWAS then produce summary statistics that reflect the strength (i.e., effect size) and direction with which SNPs are associated with the target phenotype (Choi et al., 2020). To use our book analogy, they identify differences in the letters of our book, relate them to differences in our traits, and measure the strength of this relationship. These GWAS summary statistics enable computing polygenic scores in independent samples, for whom **genotype** data are available. They do this by aggregating the SNPs identified in the GWAS, weighed by their effect size (Choi et al., 2020; Pasaniuc & Price, 2017). Polygenic scores therefore reflect person-specific estimates of genetic propensities for a given target phenotype (Plomin & von Stumm, 2018). In other words, an individual's polygenic score is a 'risk score' for a given trait, based on the differences in the letters in their genomic book.

Polygenic scores are unique predictors of psychological traits, in the way they are stable across the lifespan (i.e., they are as predictive of adult outcomes during childhood as they are in adulthood), unaffected by self-report biases (i.e., one cannot inflate or fake their polygenic scores), and preclude backward causation (i.e., inherited DNA differences are unchangeable by behavioural or environmental factors; Plomin & von Stumm, 2018). Polygenic scores can be modelled in statistical analyses, just like scores from psychometric tests or other psychological measures. While polygenic scores may be powerful predictors of people's phenotypic differences, they do not necessarily cause these differences. They are probabilistic rather than deterministic or causal predictors of phenotypic outcomes (Asbury et al., 2021; Harden, 2021; Plomin & von Stumm, 2022), and they also capture environmental influences (Okbay et al., 2022; Selzam et al., 2019; Starr et al., 2025).

Polygenic scores for children's educational achievement

To date, four large-scale GWAS have been published that used 'years spent in full-time education' as target trait (Wilding et al., 2024). The sample sizes of these GWAS increased over time, from just under 130,000 participants in 2013 to over 3 million participants in 2022 (Wilding et al., 2024; Figure 5). As the GWAS sample sizes increased, so did the predictive validity of polygenic scores based on the GWAS' summary statistics for educational attainment (Wilding et al., 2024). In 2013, polygenic scores could explain ~2% of people's differences in educational attainment (Rietveld et al., 2013). By 2022, polygenic scores explained more than 14% of people's differences in educational attainment (Okbay et al., 2022). While not directly comparable to intervention effect sizes, these estimates are sizeable: many education interventions yield effects that are modest in magnitude and account for a smaller share of variation in outcomes. A meta-analysis estimated that the polygenic scores for years spent in education based on Lee et al.'s (2018) GWAS accounted for up 25% of the variance in educational achievement (Wilding et al., 2024; see details below).

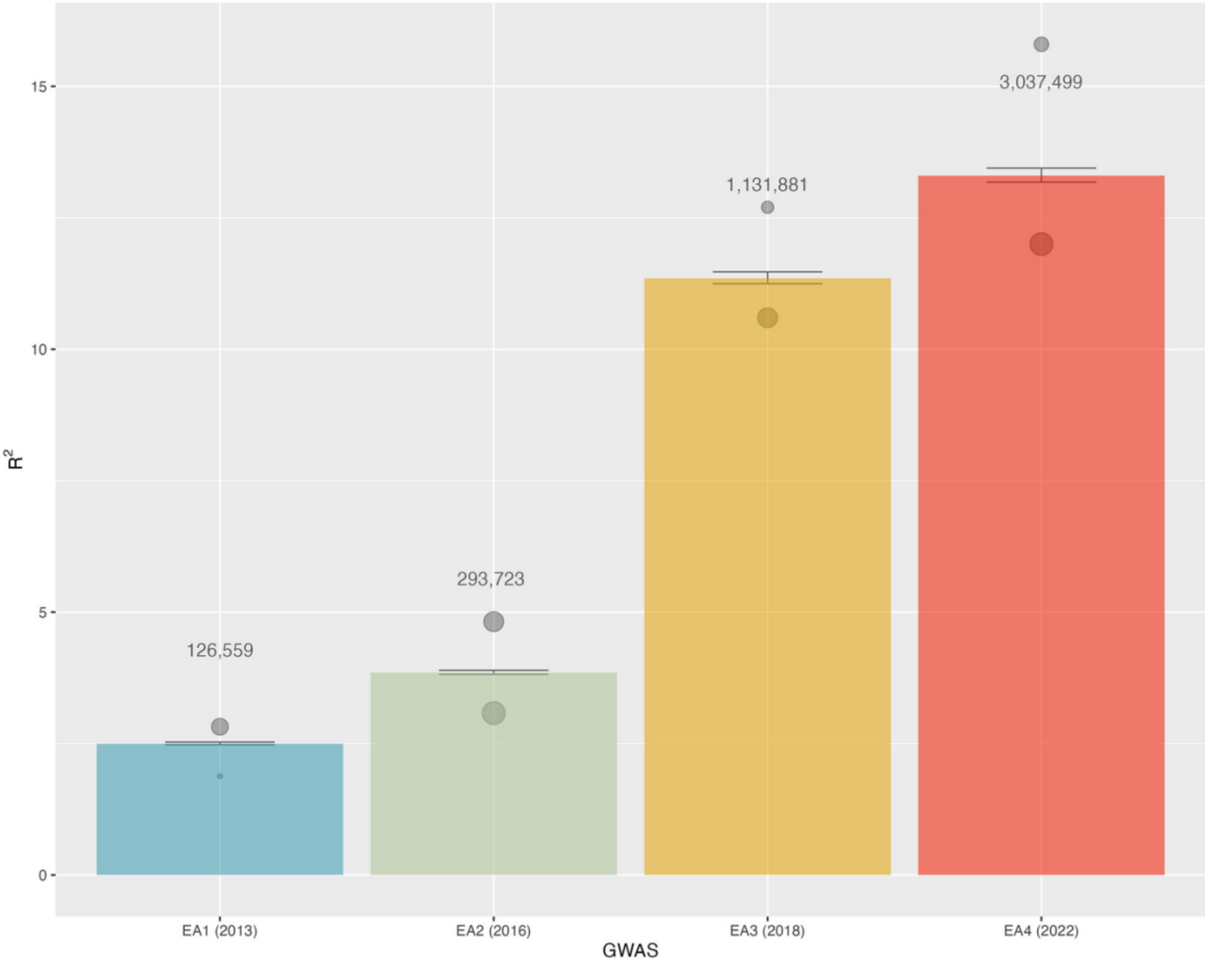

Figure 5: Polygenic score prediction of years spent in education across GWAS

Note: For each GWAS for educational attainment (EA), the year of publication (in parentheses) is shown along the *x*-axis, and the discovery sample sizes are given above their respective bar. Bars indicate the weighted mean proportion of variance (*R*2) of polygenic score predictions of educational attainment in the independent samples that were reported in the original GWAS articles. Error bars reflect 95% confidence intervals (CIs). Gray circles reflect the polygenic score prediction from each independent sample, whose *N* is indexed by circle size. The figure was adapted from Wilding et al. (2024).

Polygenic score **predictions** of educational attainment are sizeable across studies and samples (Wilding et al., 2024). Likewise, polygenic scores for years spent in full-time education are powerful predictors of children's differences in educational achievement, including school grades, teacher ratings, and scholastic test scores. The meta-analytic association in data from 83,788 participants between polygenic scores and educational achievement was 0.50 (95% CI from 0.39 to 0.61), which is considered a large effect (Wilding et al., 2024). The effect size means that a Standard Deviation increase in polygenic scores for years spent in education is associated with a difference of about two GCSE grades, according to the latest GCSE scoring system (i.e., 1 to 9, with a mean of 4.80, and SD of 2.1; https://epi.org.uk/publications-and-research/analysis-gcse-results-day-2024/).

Several other GWAS have been published for other phenotypic traits that are related to children's educational achievement. For example, polygenic scores can be computed for intelligence (Savage et al., 2018), a trait that is closely related to children's differences in educational achievement (Deary et al., 2007). A recent meta-analysis found a meta-analytic association between polygenic scores and intelligence test scores of .25 (CI 95% 0.18 to 0.30) in 452,864 participants, including adults and children (Oxley et al., 2024). This association translates into an IQ point difference of about 4 IQ scores per Standard Deviation change in polygenic scores. Other GWAS that likely captured DNA variants relevant for children's educational achievement targeted language-related phenotypes, including reading ability, dyslexia, and preschool vocabulary (Doust et al., 2022; Eising et al., 2022; Verhoef et al., 2024). Only for one of these GWAS, polygenic score predictions have been reported (Doust et al., 2022). Polygenic scores for dyslexia explained around 4% of the variance in reading and spelling measures in samples of adults and adolescents (Doust et al., 2022). Overall, multiple GWAS have been published that allow computing polygenic scores for children's education-related traits. On average, these polygenic scores tend to be significantly and positively associated with education-related traits in independent samples, albeit effect sizes vary.

For the current project's analyses, we summed multiple polygenic scores across three GWAS studies. The first GWAS specified years spent in full-time education as target trait (Lee et al., 2018). This GWAS is the foundation of a vast number of polygenic score studies in education, because it achieved the great power to detect relevant DNA variants (see above and Figure 5). The summary statistics of the GWAS for years spent in full-time education (Lee et al., 2018) have been openly shared in full, enabling the computation of polygenic scores with high predictive validity in E-Risk. Years spent in full-time education is a broad trait that is associated with all constructs that are key to this research, including mothers' SES and speech and children's cognition, literacy, and educational achievement. We also built polygenic scores from two further GWAS that were more specific to verbal abilities, including reading- and language-related skills (Eising et al., 2022) and dyslexia (Doust et al., 2022). These GWAS have much smaller discovery samples than the one for years spent in education. Accordingly, polygenic scores based on these two GWAS tend to have lower predictive validity than the polygenic scores for years spent in education. Yet, we included polygenic scores based on these 'smaller' GWAS here to capture a broad range of genetic variants associated with education and speech in both mothers and children.

Our project's approach

To elucidate the role that mothers' speech plays for transmitting family background inequality in education (Golinkoff et al., 2019; Hoff, 2013; Kidd et al., 2018), we adopted a multifaceted methodology that addressed several gaps in previous research.

First, we capitalised on data collected from a socioeconomically diverse sample of mothers in England and Wales when their twin children were 5 years old and starting primary school (Caspi et al., 2004). The mother-child trios participated in E-Risk, a UK cohort study of twin families, who were identified via the Office for National Statistics' multi-birth register (Moffitt & E-Risk Study Team, 2002) and represent the full range of Britain's socioeconomic conditions. E-Risk families' residential addresses have been matched to the UK Index of Multiple Deprivation distribution: 25% of the families lived in Britain's wealthiest and 25% in the poorest areas (Odgers et al., 2012). Also, because E-Risk has suffered minimal attrition since its inception (~5%), in contrast to many other longitudinal studies (Gustavson et al., 2012), the sample's representativeness remained intact over time. Using a large representative sample enhances the generalisability of our findings. Unlike previous studies, which often focused on small and homogeneous populations (d'Apice et al., 2019; Nielsen et al., 2017), our sample allowed us to examine various family backgrounds and their associations with mothers' speech and children's education-related outcomes.

Prior studies in this area have primarily focused on speech that children are exposed to during the early years when they first acquire language (Hart & Risley, 1995; Rowe, 2018), but little attention has been paid to the role of mothers' speech when children are of school age. Earlier studies also failed to test long-term associations between mothers' speech characteristics and children's educational achievement over the school years, which coincide with the transition from childhood to adolescence. Our analyses here spanned children's educational outcomes from age 5 through 18 years. This broad age range allowed testing whether associations between mothers' speech and children's education-related outcomes persist over the course of primary and secondary school years. Previous studies in this area only reported on children's development during the early years but not over the course of formal education.

We also incorporated genetic measures (i.e., education polygenic scores) to disentangle the gene-environment interplay in the transmission of family background inequality. Using polygenic scores for both mothers and children allowed us to control for genetic confounding and to assess the extent to which the transmission of family background inequality occurs through environmental pathways, specifically mothers' speech. Our genetically sensitive research design helps elucidating the extent to which associations between mothers' speech and children's education-related outcomes can be attributed to their shared genetics, to environmental factors that are genetically driven by the parents (i.e., genetic nurture), and to environmental influences that are independent of genetics (i.e., nurture). Overall, our approach provides a comprehensive examination of the role of mothers' speech in perpetuating family background inequality, offering new insights for future research, policy, and interventions aimed at reducing educational inequality.

Aims and Research Questions

Our principal aim was to address four key research questions:

1. Does family background predict mothers' speech? We tested whether mothers' lexicon and grammar varied as a function of their SES (i.e., occupation, educational attainment, and household income). Each socioeconomic indicator was modelled independently to its prediction of mothers' differences in speech.
2. Does mothers' speech predict their children's education-related outcomes? We tested whether mothers' speech predicted children's education-related outcomes from age 5 through 18 years, focusing on (a) cognition and literacy (as indicated by standardised tests; Torgersen et al., 1999; Wechsler, 1989), and (b) educational achievement (English and Mathematics performance as rated by teachers), as well as on children's educational attainment (i.e., highest educational qualification obtained at age 18 years).
3. Does mothers' speech mediate the association between family background and education-related outcomes? We tested the extent to which mothers' speech mediated the influence of family background, operationalised by mothers' SES, on children's educational-related outcomes.
4. To what extent is the role of mothers' speech in the transmission of family background inequality in education influenced by genetics? To answer our fourth research question, we incorporated mothers' and children's genetic propensities for language and education-related outcomes, as captured by polygenic scores, in our analyses.

Methodology

The sample

Data came from the Environmental Risk (E-Risk) Longitudinal Twin Study, which tracks the development of 2,232 British twin children who were drawn from a larger birth register of twins born in England and Wales in 1994 and 1995 (Trouton et al., 2002). Full details about the sample are reported elsewhere and available online (www.eriskstudy.com; Moffitt & E-Risk Study Team, 2002). To summarise, the E-Risk sample was constructed in 1999 to 2000 when 1,116 families (93% of those eligible and of whom 90.4% were Caucasian) with same-sex 5-year-old twins participated in home-visit assessments. This sample comprised 56% monozygotic and 44% dizygotic twin pairs; sex was evenly distributed within zygosity (49% male). Families were recruited to represent the UK population of families with newborns in the 1990s, on the basis of residential location throughout England and Wales and mothers' age (i.e., older mothers having twins via assisted reproduction were under-selected and teenage mothers with twins were over-selected). This resulted in a sample of families which were representative of the distribution of neighborhood socio-economic status across the UK population (Odgers et al., 2012).

Follow-up home visits were conducted when children were aged 7, 10, 12, and 18 years (participation rates were 98%, 96%, 96%, and 93%, respectively). Home visits at ages 5, 7, 10, and 12 years included assessments with participants and their mother (or primary caregiver); a different interviewer assessed each participant in a twin pair. With parents' permission, questionnaires were posted to the children's teachers, who returned questionnaires for 94% of children at age 5, 91% of the 2,232 E-Risk children (93% of those followed up) at age 7, 86.3% of the 2,232 E-Risk children (90.1% of those followed up) at age 10, and 80% of the 2,232 E-Risk children at age 12 (83% of those followed up). The Joint South London and Maudsley and Institute of Psychiatry Research Ethics Committee approved each study phase. Parents gave informed consent, and twins gave assent between 5 and 12 years and then informed consent at age 18.

Corpus of mothers' speech

This section describes how mothers' speech was collected, processed, and quantified for analysis.

Qualitative interviews: Five Minute Speech Samples

As part of the E-Risk cohort study, when their twin children were 5 years old, mothers were asked to speak for 5 to 10 minutes about each of the children separately during home visit assessments (Caspi et al., 2004). Mothers were encouraged to talk freely with few interruptions. However, if a mother found this difficult, the interviewer could aid her with a series of semi-structured probes, such as ‘In what ways would you like [child] to be different?’ Interviews about each twin were separated in time by approximately 90 minutes. All interviews were audiotaped with the mothers’ consent. Interview data was missing for 6% of the sample because some mothers did not wish to be audiotaped, because of technical problems with the tape, or because of loss to follow-up. In total, 336 hours of recordings from 1,049 speakers were available.

The interview method was adapted from the five-minute sample procedure used in previous research (e.g., Magaña et al., 1986). In E-Risk, researchers were trained to code mothers’ expressed emotions as they listened to the interviews. Prior studies using these data showed that mothers’ expressed emotions predicted children’s later levels of antisocial behaviour (Caspi et al., 2004). Recently, the same interview recordings have been used to develop machine-learning techniques for automatically coding expressed emotion (Mirheidari et al., 2024). Together, the earlier studies and findings using the E-Risk interview data illustrate that the recordings were of adequate length and quality for large-scale linguistic analysis.

Transcription and coding

A detailed, stepwise transcription and coding procedure was developed to prepare the recordings of mothers’ interviews for linguistic analysis. After an external transcription company transcribed the 336 hours of interviews verbatim, further transcription and coding were carried out in three phases. Over the period of a year (March 2023 to March 2024), up to 12 researchers were engaged and trained to format, code, clean, and quality-control the interview transcripts. These steps are important because they ensure that our measures of mothers’ speech are reliable, comparable across participants, and suitable for large-scale linguistic analysis.

Phase 1: CHAT

The first phase focused on standardising transcripts for automated linguistic analysis. We ensured all transcripts followed CHAT guidelines for automatic analyses using the Computer Language Analysis (CLAN) program (MacWhinney, 2000). The CLAN program is used to transcribe audio files using a standard set of rules specific to spoken language, also known as 'CHAT format'. Transforming existing transcriptions into the CHAT format involved, but was not limited to, coding all lines of mothers' speech (as opposed to those of interviewers), identifying instances of wordplay and interruptions during the interview, marking non-linguistic elements (for example, sighs and laughs) and marking utterances with unintelligible speech. After one of the 12 researchers completed these steps, another researcher checked the transcripts for correct format and compliance with the CHECK program, a CLAN analysis requirement.

Phase 2: Morphosyntactic information

This phase added grammatical information to enable analysis of sentence structure. We used the MOR program in CLAN. The MOR program automatically tags each word in a transcript with its morphosyntactic information. This includes parts of speech (e.g., nouns, verbs, adjectives) and morphological markers (e.g., tense, number, case). The program relies on being able to identify the lexicon and grammar of each word to mark the grammatical structure of the whole utterance. Therefore, each transcript was individually checked for words not recognised by the MOR system and were either added to the MOR dictionary, recorded as a dialectal variation of a known word (e.g. 'gonna' coded as a dialectal form of 'going to') or marked as a non-word.

Phase 3: Coding checks

In the third and final phase, transcripts were validated and checked against the original audio recordings. This phase ensured the accuracy and quality of the transcripts relative to the original audio recordings. Our first aim was to check that the start and end of mothers' utterances in speech were correctly coded to enable accurate grammatical analysis. The second aim was to re-check the transcripts to ensure they accurately matched the mothers' speech in the original recordings. Researchers were trained to recognise and code the start and end of utterances in speech. The trained researchers listened to the digitised audio tapes alongside the transcripts to ensure utterances were correctly coded and the transcript was of sufficient quality for analysis. Transcripts of poor quality were validated and checked by another researcher. Across all phases, 10% of interviews were excluded due to poor audio quality, linkage errors, or recording difficulties. This process of quantifying qualitative interviews for linguistic analysis in CLAN has been made publicly available on the GitHub open-source platform (https://github.com/annabrown2/TranscriptAnalysis_WithCLAN).

Mothers' speech corpus for analysis

After preprocessing, we constructed the final speech corpus used in our analyses. Once all transcripts were checked and collated, 2% of families were excluded because a language other than English was spoken at home. Our final analysis sample included all mothers and their twins for whom sufficient speech data was available (i.e., 1,788 children from 894 families; 80.1% of the original E-Risk sample).

Given the varying interview lengths, 10-minute excerpts were taken from each transcript to ensure the comparability of speech across mothers. For lexical markers, we extracted mothers' vocabulary sophistication and lexical diversity. As grammar markers, we extracted a grammatical complexity index, mean length of utterance (morpheme count), and verb usage within utterances. For the extraction, we used the FREQ, VOCD, and MLU programs within CLAN. FREQ is a program that generates frequency counts of words, morphemes, or other linguistic features in a transcript. The command was used to quantify vocabulary sophistication, grammatical complexity index, and verb index. VOCD was used to extract a measure of lexical diversity and is a tool for calculating D-scores in a transcript. It is an improvement on older methods like the Type-Token Ratio (TTR) because it accounts for the fact that longer transcripts naturally lead to lower ratios (as the number of repeated words increases (McCarthy & Jarvis, 2010). MLU is a program which measures the mean length of utterance (MLU) and calculates the average number of morphemes per utterance. Each language marker is described in detail below. These linguistic markers were selected to capture different dimensions of mothers' speech that may be relevant for children's learning skills and educational outcomes.

Lexical Markers

Vocabulary sophistication

Vocabulary sophistication was measured by computing the percentage of rare words used in the sample. From the transcripts, we removed all words on the Dale-Chall word list, as well as their inflected forms, all non-dictionary words, and any derivations of family names. The Dale-Chall word list includes the 3,000 most common words known by fourth graders (Chall & Dale, 1995; Dale & Chall, 1948). Any remaining words in the transcripts were considered rare and sophisticated words. We then calculated the percentage of rare word types by the total number of word types in the sample.

Lexical Diversity

Lexical diversity was measured by computing D-scores. D-scores are based on the probability of introducing a new word as the speech sample progresses. D-scores are extremely robust against sample size effects and thus constitute reliable markers of lexical diversity, over other methods such as Type Token Ratio (Malvern et al., 2004; McKee, Malvern, & Richards, 2000; Owen & Leonard, 2002).

Grammar Markers

Grammatical complexity index

Grammatical complexity (GCI) was computed by calculating the total number of grammatical relations that mark syntactic embeddings divided by the total number of grammatical relations (Mueller, Koscik, Clark, et al., 2018; Mueller, Koscik, Hermann, et al., 2018). The higher the index, the more complex grammatical and syntactic structures used in speech.

Verb index

Verb index was computed by calculating the total number of verbs divided by the total number of utterances. The higher the average number of verbs per utterance the more complex syntax used in utterances.

Mean Length of Utterance

MLU was calculated by dividing mothers' total number of morphemes by their total number of utterances produced. The higher the MLU, the more complex and longer a person's utterances (Ezeizabarrena & Garcia Fernandez, 2018). Any words classed as communicators, such as 'oh' or 'ah', were excluded from this analysis.

Validation of speech markers

Analyses were carried out to validate the reliability of our speech markers. First, we calculated whether our markers correlated within marker constructs. Lexical markers (vocabulary sophistication and lexical diversity; Figure 6) were positively correlated at .34. Because the inter-correlation between vocabulary sophistication and lexical diversity was below .60, we treated them as indexing independent constructs throughout our analyses. Grammar markers (MLU, grammatical complexity and verb usage) were also positively correlated between .79 and .91. Because these correlations exceeded .60, we computed an overall grammar composite by summing the z-scores for grammatical complexity, verb usage, and MLU. These composite scores are referred to as grammatical complexity throughout the rest of the report.

We then tested whether our speech markers correlated across marker constructs. We found positive but modest correlations between all speech markers (Figure 6), suggesting that our measures captured different aspects of the broader construct space of mothers' speech (i.e. vocabulary sophistication, lexical diversity, and grammatical complexity). This pattern indicates that our measures capture related but distinct aspects of mothers' speech.

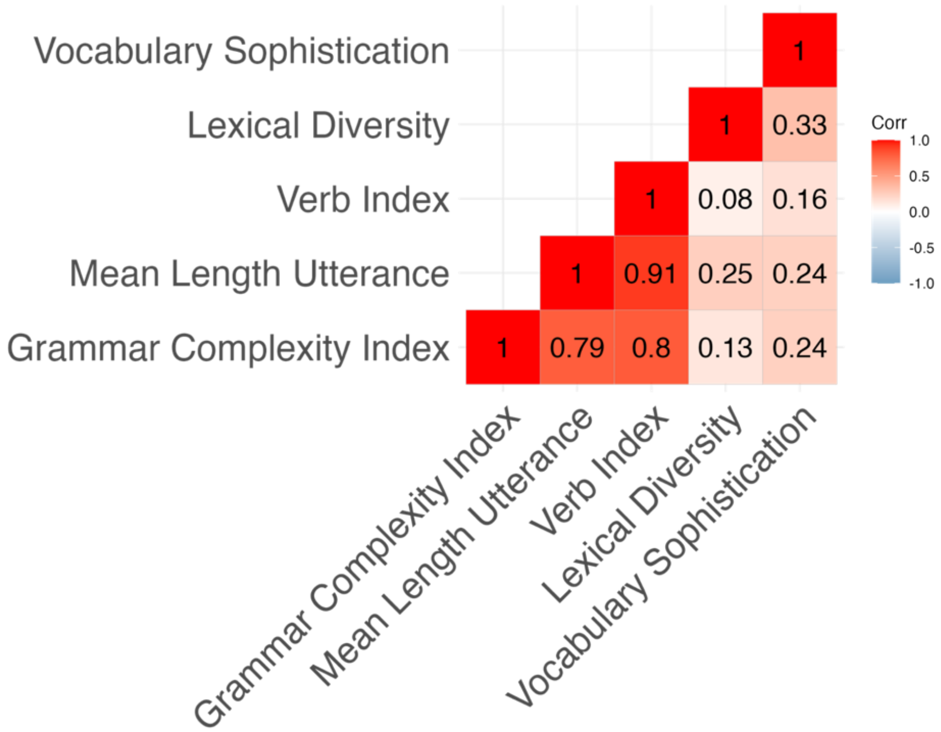

Figure 6: Correlations between markers of mothers' speech

Note: Pearson's correlations are based on N = 894. Red colours indicate positive correlations; darker shades indicate stronger correlations.

To further validate the markers of mothers' speech, we tested their correlations with mothers' scores on the reading subtest of the wide-range achievement test (WRAT-3; Snelbaker et al., 2001). The WRAT-3 takes ~15– to 30 minutes to complete, is individually administered, and captures individual differences in basic academic skills, including reading, spelling, and arithmetic. Grammatical complexity, lexical diversity and vocabulary sophistication correlated with mothers' reading scores from the WRAT-3 at .12, .17 and .40, respectively. These correlations suggest that mothers with higher reading scores tended to construct more grammatically complex sentences, use a wider range of vocabulary, and make more sophisticated word choices in their speech. Thus, the characteristics of mothers' speech that we quantified here can be considered reliable indicators of the mothers' overall verbal ability. Mothers' complexity of speech and WRAT-3 scores have been shown elsewhere to be highly correlated (Golden & Bennett, 2024), which aligns with our findings here.

Children's education-related outcomes

Verbal and non-verbal ability

A short form of the Wechsler Preschool and Primary Scale of Intelligence-Revised (Wechsler, 1989) was used to assess the cognitive ability of young children at age 5 years. Two subtests were administered: a score on the Vocabulary Subtest taken as a measure of verbal ability and a score on the Block Design subtest taken as a measure of non-verbal ability. All raw scores were converted to age-based standard scores.

Reading score

Children completed The Sight Word Efficiency (SWE) subtest of the Test of Word Reading Efficiency (TOWRE), which measures a child's ability to pronounce printed words accurately and fluently (Torgesen et al., 1999). The SWE was administered at ages 7 and 10 years to assess the number of real printed words that children can identify accurately within 45 seconds. All raw scores were converted to age-based standard scores. The Sight Word Efficiency subtest has high internal consistency and developmental sensitivity (Tarar et al., 2015), is associated with oral language development (Killingly et al., 2025), and correlates strongly with comprehension measures (Babayiğit, 2015).

Educational achievement

Teachers rated the children's performance in English and Mathematics when the twins were aged 7, 10, and 12 years. Teachers compared the target child's performance to that of a typical student of the same age on a 5-point Likert scale (1=Far Below, 2=Somewhat Below, 3=Average, 4=Somewhat Above, 5=Far Above). The ratings for English and Mathematics were summed into a single measure of educational achievement.

Mothers' family background

Mothers' educational attainment

Mothers' highest educational qualifications when the children were 5 years old were coded into 5 groups (1= No Qualifications; 2 = Certificate of Secondary Education (2-5)/General Certificate of Secondary Education (D-G), i.e. below average school leaving qualification; 3= Certificate of Secondary Education (1)/O Level (A-C)/ General Certificate of Secondary Education (A-C), i.e. above average school qualification; 4= Advanced Level/Scholarship Level; 5=Higher National Certificate/Degree i.e., College Level Qualification; 6= Higher National Diploma/Postgraduate degree).

Mothers' occupation

Mothers' current (or most recent) occupations when the children were 5 years old were coded using the Office of Population Censuses and Surveys (1991) Standard Occupational Classification. Occupational groups are arranged into six social classes (1=professional occupations; 2=managerial and technical occupations; 3=skilled occupations (non-manual); 4=skilled occupations (manual); 5=partly skilled occupations; 6=unskilled occupations).

Household income

Mothers reported the household's total income from all sources before tax in the previous 12 months when the children were 5 years old. Families were then coded into 16 income brackets, the lowest bracket representing an annual income of £10,000 or less and the highest representing an annual income of £40,000 or more.

Children's and mothers' genetic propensities

Mothers and children in E-Risk have been genotyped. Using these genotype data, we computed polygenic scores for both mothers and children. We used the summary statistics from the GWAS for the target phenotypes years spent in education (EA3; Lee et al., 2018), reading- and language-related skills (Eising et al., 2022), and dyslexia (Doust et al., 2022). We selected these GWAS to capture a broad range of genetic variants associated with education and speech in both mothers and children. For EA3 (Lee et al., 2018), the full summary statistics were released by the Social Science Genetic Association Consortium (https://www.thessgac.org). For reading- and language-related skills (Eising et al., 2022), we used the complete summary statistics for word reading, nonword reading, spelling, and phoneme awareness. For dyslexia (Doust et al., 2022), summary statistics for the top 10,000 hits were available and used. Polygenic scoring in E-Risk has been described in detail elsewhere (Agnew-Blais et al., 2022). We fitted so-called LASSO regression models to select the polygenic scores that added significantly to the prediction of (a) mothers' educational attainment and vocabulary and (b) children's educational attainment. All three models converged on the same polygenic scores, including years spent in education (Lee et al., 2018), dyslexia (Doust et al., 2022), and word and non-word reading (Eising et al., 2022). We averaged the polygenic scores from the three GWAS within persons to index mothers' and children's genetic propensities.

Analytical approach

To answer our first research question, whether mothers' SES conditions their lexicon and grammar, we built regression models with each speech characteristic (i.e., mothers' vocabulary sophistication, lexical diversity, and grammar score) as an outcome. Mothers' SES indicators, including highest educational attainment, household income, and occupation, were added as predictors to the models. We also included mothers' age in years at first birth in all models to control for any confounding due to the age of the mothers.
To address research question 2, whether mothers' speech predicted children's education-related outcomes, we used a mix of linear regression and latent growth curve models. To predict children's learning skills (i.e., verbal skills, non-verbal skills, and literacy skills) from mothers' speech characteristics, we fitted separate linear regression models at each age (i.e., 5 to 12 years). Children's verbal and nonverbal abilities (i.e., cognition) were assessed at age 5 years, and literacy skills were assessed at the ages 7 and 10 years. To predict children's educational achievement, we fitted latent growth curve models to test associations between mothers' speech and teacher ratings of school performance at the ages 7,10 and 12 years (see Figure 7). Here, we modelled educational achievement as two latent growth factors: children's stable differences in educational achievement (i.e., the intercept) and their improvements and decreases in educational achievement over the years (i.e., the slope). The intercept reflects children's differences in educational achievement that could be observed at the first assessment age (i.e., at age 7 years) and remained stable over the study period (i.e., until age 12 years). The sample's intercept reflects the average performance level of the sample at age 7 years. The extent to which the intercept of individual children exceeds the sample's mean intercept reflects that these individual children started at a higher level of achievement relative to others. The slope represents the systematic, linear changes in educational achievement from age 7 to age 12. On average, the slope is zero in the overall sample, but changes occur for individual children. A positive slope indicates that a child improved in educational achievement over time (i.e., gains in

performance), while a negative slope suggests worsening educational achievement (i.e., loss or decline in performance). The slope captures the degree and direction of change, showing whether children are improving or worsening in their school performance from the initial starting point, and to what extent.

Latent growth curve models allow exploring how mothers' speech may contribute to children's educational achievement over time. For example, these models can help identify whether mothers' speech is associated with a performance advantage for children already at the beginning of school, which would be reflected by a positive association between mother' speech markers and the intercept latent growth factor. They can also show whether mothers' speech contributes to improving children's school performance over time, a finding that would be indicated by a positive association between mothers' speech markers and the slope growth factor. Likewise, latent growth curve models can reveal whether specific speech or SES markers predict gains or declines in educational achievement over time.

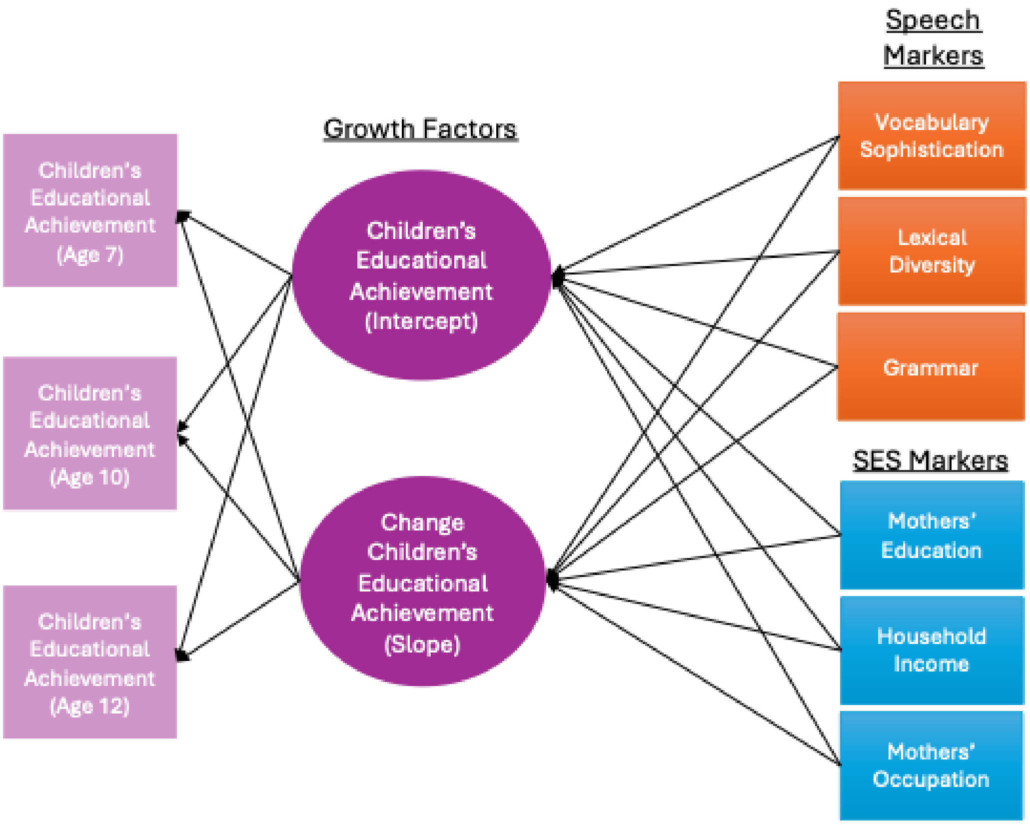

Figure 7: Predicting children's long-term educational achievement from mothers' speech and SES

Note: This model depicts the influence of mothers' speech and SES on the latent growth factors of intercept and slope of children's educational achievement. Squares represent directly observed and measured variables; circles represent latent factors.

To address research question 3, to what degree mothers' speech explains the association between mothers' SES and children's education-related outcomes, we conducted mediation models. Our approach to was motivated by the conceptual logic of mediation (Baron & Kenny, 1986; MacKinnon et al., 2007) but was not contingent on their significance-testing framework. Instead, we applied mediation models to quantify the relative contribution of mothers' speech to the SES–outcome association, which provided an effect-size estimate of the indirect pathway (i.e., the path from mothers' SES to children's education-related outcomes via mothers' speech). Based on our prior regression analyses, we selected those markers of mothers' speech as mediators that were significantly associated with both SES and children's education-related outcomes (see research question and 2 above). We used bias-corrected bootstrapped confidence intervals (95% CI, 1,000 resamples) to estimate the indirect effects (Li, 2011). To compare the proportion of variance explained by indirect and direct effects, we calculated mediation percentages (Hayes, 2009; Zhao et al., 2010). According to the conceptual logic of mediation analysis, three conditions must be met (MacKinnon et al., 2007). First, the mediator (i.e., mothers' speech) must be significantly associated with the predictor (i.e., mothers' SES). Second, the mediator must significantly predict the outcome (i.e., children's education-related outcomes). Third, the predictor must also significantly predict the outcome (i.e. mothers' SES predict children's education-related outcomes). The effect of SES on children's education-related outcomes reflects the direct effect (Figure 8). The effect of SES via mothers' speech reflects the indirect effect (Figure 8). Full mediation happens when the direct effect path becomes non-significant after adding the indirect effect. In this case, mothers' speech would fully account for the link between SES and children's education-related outcomes. Partial mediation occurs when both indirect and direct effects remain significant. Here, mothers' speech would only partially explain the link between SES and children's education-related results. Partial mediation also suggests that there are additional pathways through which mothers' SES influences children's education-related outcomes. These additional pathways are yet to be identified (i.e., they were not modelled within the scope of the current research).

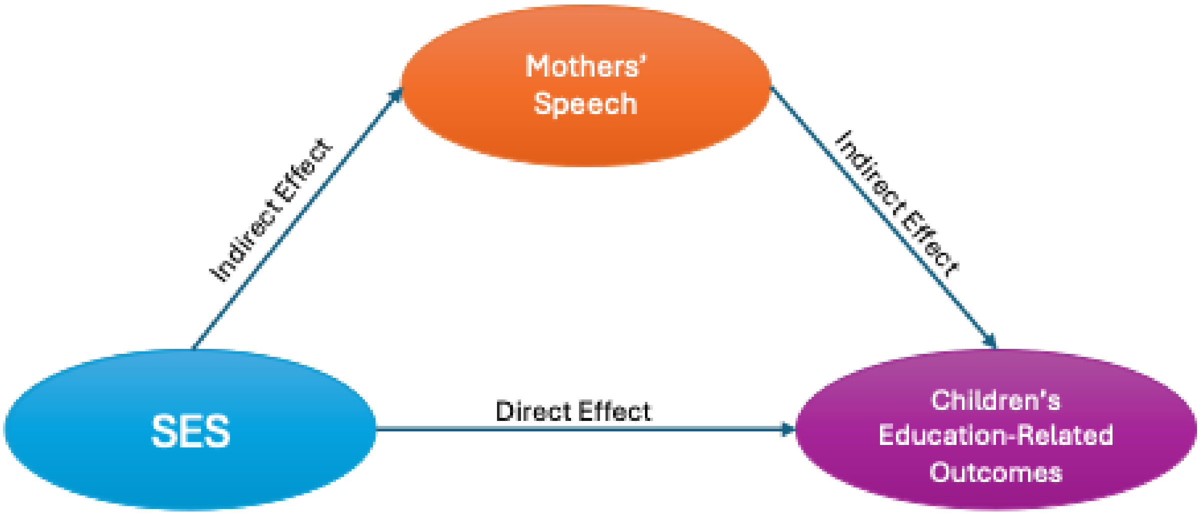

Figure 8: Mothers' speech as mediator of the association between mothers' SES and children's education-related outcomes

Note: The mediation model compares the direct effect of SES on children's education-related outcomes to the indirect (mediated) effect of SES on children's outcomes through mothers' speech.

To address our research question 4, to what extent the role of mothers' speech in the transmission of family background inequality was influenced by genetic factors, we focused on the association between mothers' and children's educational attainment. Mothers' highest educational qualification was recorded at twins' age 5 years, while twins' highest educational qualification was recorded at age 18 years. We used polygenic scores to capture mothers' and children's genetic propensities for education-related outcomes (i.e., their probability, inferred from aggregates of inherited DNA variants, to do well in school and education). We specified the associations from polygenic scores to mothers' and children's educational attainment in the direction from genotype to phenotype because the reverse is not plausible (i.e., one's phenotypic education cannot change one's inherited DNA differences that are fixed at conception). In these analyses, we focused on mothers' vocabulary sophistication to index speech, because mothers' vocabulary sophistication was the strongest correlate of mothers' SES and predictor of children's education-related outcomes in our earlier analyses (research questions 1-3).

We fitted a series of path models to disentangle transmission pathways of education due to genetics, genetic nurture, and nurture. Our models are detailed in Figure 9. First, we tested (i) the prediction from mothers' educational attainment for children's educational attainment and the extent to which this association was mediated by mothers' vocabulary sophistication. This model is akin to the mediation models described above (research question 3; Figure 8). We then extended this environmental transmission model to become a genetically sensitive model (ii) by adding children's and mothers' genetic propensities for education, as indexed by polygenic scores. The genetically sensitive model allows discerning genetic confounding, genetic nurture, and nurture effects. Finding genetic nurture and nurture effects would indicate that mothers' vocabulary plays a causal role in shaping children's educational attainment, because these effects are independent of shared genetic variance between mothers and children.

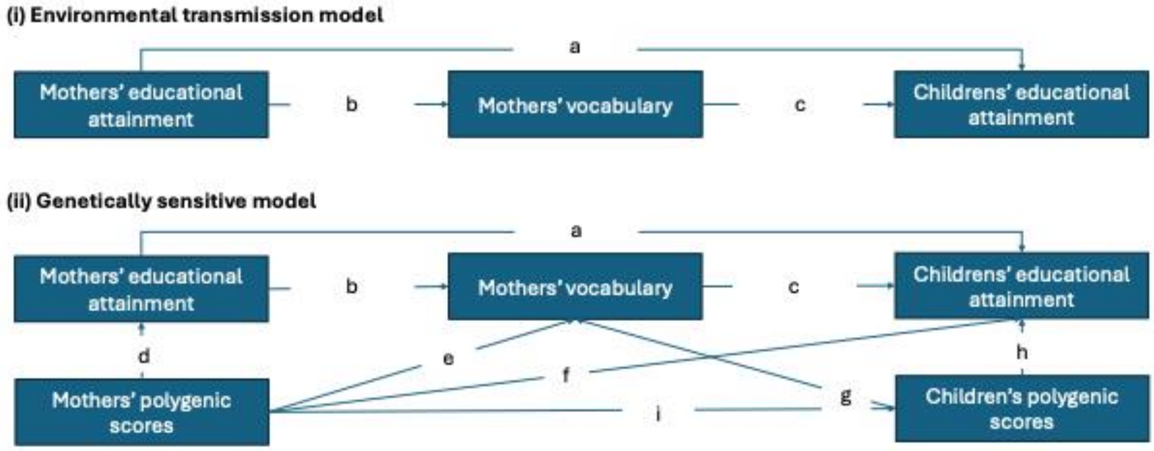

Figure 9: Models of the educational attainment transmission from mothers to children

Note. The environmental transmission model (i) tests the prediction from mothers' educational attainment to children's educational attainment (path a) and the extent to which this association is mediated by mothers' vocabulary sophistication (b*c). The genetically sensitive model (ii) discerns (1) genetic nurture effects that are mediated by mothers' educational attainment (d*a), by mothers' vocabulary sophistication (e*c), by non-specified environments (f), and by mothers' educational attainment and vocabulary sophistication (d*b*c); (2) effects of genetic transmission from mothers to children (i.e., i*h); and (3) gene-environment correlation (g), which reflects mainly influences from the genetic variants that children inherited from their fathers, because mothers' (i) are controlled. The influence of nurture (i.e., effects independent of genetics as captured by polygenic scores) can be inferred from the proportion of variance that path a + b*c account for relative to that of the sum of all other transmission paths in model (ii), in addition to genetic confounding (paths a in model (i) compared to model (ii)). The figure is adapted from von Stumm et al. (2026).

Summary of Key Findings

Research Question 1: Does family background predict mothers' speech?

We tested the extent to which the characteristics of mothers' speech were associated with indicators of their SES, including their education, occupation, and household income. Mother's SES indicators accounted additively for 28% of the differences in mothers' vocabulary sophistication, for 6% in lexical diversity, and for 2% in mothers' grammatical complexity (not significant; Figure 10). Mothers' educational attainment was the strongest independent correlate of vocabulary sophistication, sharing 9% of the variance, followed by household income and occupation, which each accounted for 5% of the variance. Household income also accounted for 4% of the variance in lexical diversity, but no other significant SES associations with mothers' speech were observed. Although these effects are modest in size, they may still be meaningful at the population level, where small differences can accumulate across individuals and over time. Sensitivity analyses showed that the effect sizes were robust after controlling for mothers' scores on the reading subtest of the wide-range achievement test (WRAT-3; Snelbaker et al., 2001). Importantly, the absence of significant associations for grammatical complexity and most indicators of lexical diversity helps rule out the possibility that SES is broadly related to all aspects of mothers' speech. Overall, the findings suggest that mothers' SES is more strongly and consistently associated with their vocabulary sophistication than with their lexical diversity and grammar.

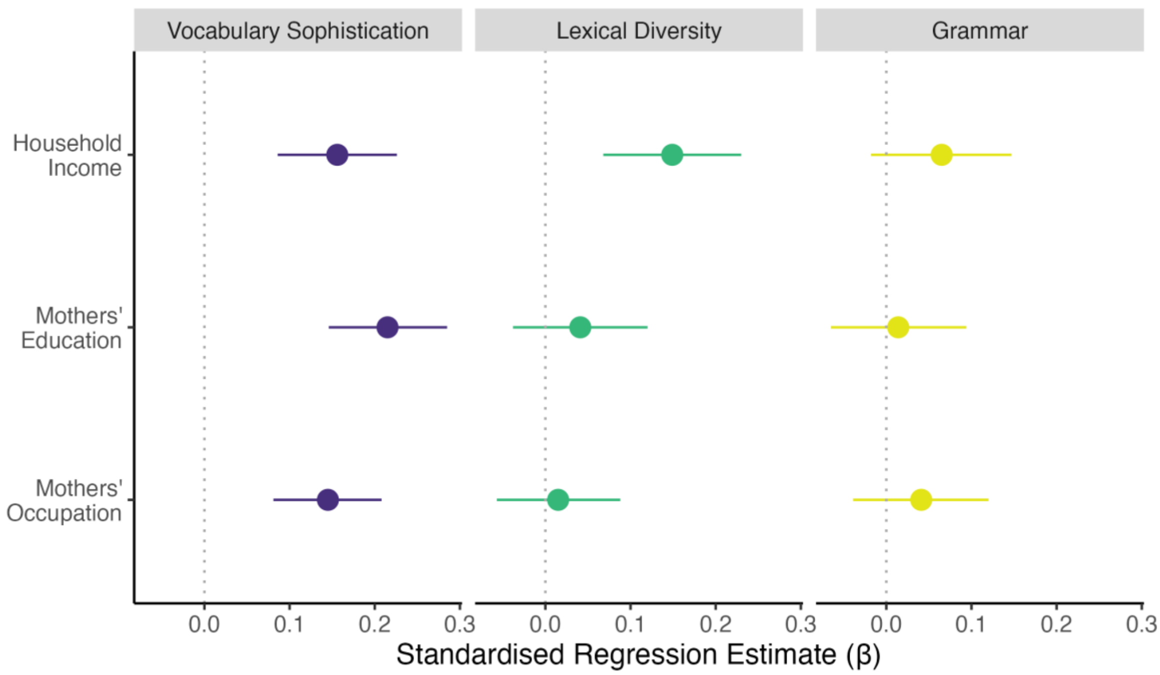

Figure 10: Mothers' education, occupation, and household income as predictors of their speech

Note: N = 894 mothers. Dots represent standardised regression (beta) estimates from models where mothers' education, occupation, and income were included as simultaneous predictors after adjusting for mothers' age in years. The lines indicate the 95% confidence intervals. Figure adapted from Brown et al. (2025).

Overall, we found some support for the hypothesis that mothers' speech differences align with their socioeconomic conditions. Our findings align with the previous research literature, which includes reports of dramatic SES-related differences in mothers' speech, albeit in smaller samples (e.g., Hoff-Ginsberg, 1998; Huttenlocher et al., 2010; Rowe, 2008). In studies that analysed data from larger-scale cohorts, such as the current project, the relationship between mothers' SES and their speech appeared weaker (Bergelson et al., 2023; Kelly et al., 2011), akin to our findings here.

We observed the strongest and most consistent SES-associations for mothers' vocabulary sophistication, which varied significantly as a function of all three SES markers (i.e., household income, education, and occupation). These findings suggest that mothers' vocabulary sophistication is a plausible factor in the transmission of family background inequality, while lexical diversity and grammatical complexity are less likely to play a meaningful role. It should be noted that characteristics of mothers' speech other than those studied here may relate to mothers' SES, such as dialect (Curtin, 2020), word pronunciation (Kraus et al., 2019), and narrative construction (Ochs & Schieffelin, 2017). The contexts in which speech is used may also play a role here. A meta-analysis observed a relationship between SES and mothers' speech only in the context of child-directed speech but not in other contexts, such as overheard conversations (Dailey & Bergelson, 2022). In summary, our findings suggest that vocabulary sophistication, but not lexical diversity and grammatical complexity, covary in meaningful ways with mothers' education, occupation, and household income, which are typical markers of SES. Alternative speech characteristics than the ones studied here may serve as additional pathways through which family background inequality in education becomes transmitted.

Research Question 2a: Does mothers' speech predict their children's cognition and literacy?

We tested each marker of mothers' speech as a predictor of children's cognition (i.e., verbal and non-verbal ability at age 5 years) and literacy (i.e., reading skills at age 5 and 7 years). Mothers' vocabulary sophistication was significantly and positively associated with children's cognition and literacy (Figure 11), accounting for 2-5% of the variance across ages and measures. Although these effect sizes are modest, they may still be meaningful at the population level, where small differences can accumulate over time and across individuals. Neither mothers' lexical diversity nor grammar significantly predicted children's cognition and literacy (Figure 11). This pattern of null findings suggests that associations with children's outcomes are not uniform across all aspects of mothers' speech, but may be specific to vocabulary sophistication. Our findings suggest that the children of mothers, who use more sophisticated vocabulary (i.e., words that are less common in speech), tend to show better verbal, non-verbal, and reading skills. Our findings also confirm, in line with the results for research question 1, that mothers' vocabulary sophistication likely plays a distinct role for children's cognition and literacy development.

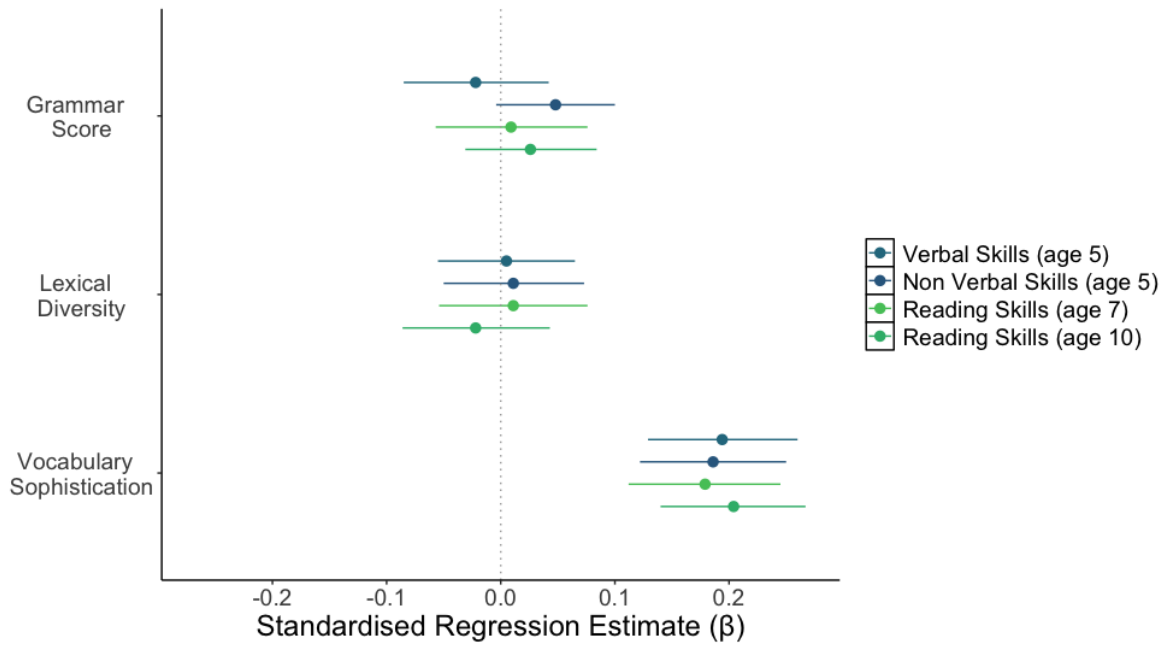

Figure 11: Predicting children's cognition and literacy from mothers' speech

Note: N= 894 families. Dots represent standardised (beta) regression estimates, and lines represent 95% confidence intervals. All models were adjusted for mothers' age. Figure adapted from Brown et al. (2025).

Next, we modelled whether mothers' SES predicted children's cognition and literacy (Figure 12). Across ages and measures, mothers' SES indicators accounted for 8-10% of the variance in children's cognition and literacy (Figure 12). Out of the three SES indicators, only mothers' educational attainment and household income significantly predicted differences in children's outcomes. Each of these two accounted independently for 3-4% of the variance in children's cognition and literacy across ages and measures. Mothers' occupation was not significantly associated with children's cognition and literacy at any age. In sum, children, whose mothers had higher educational qualifications and greater household income, scored better on standardised tests of verbal, non-verbal, and reading skills than children, whose reported lower education and income levels.

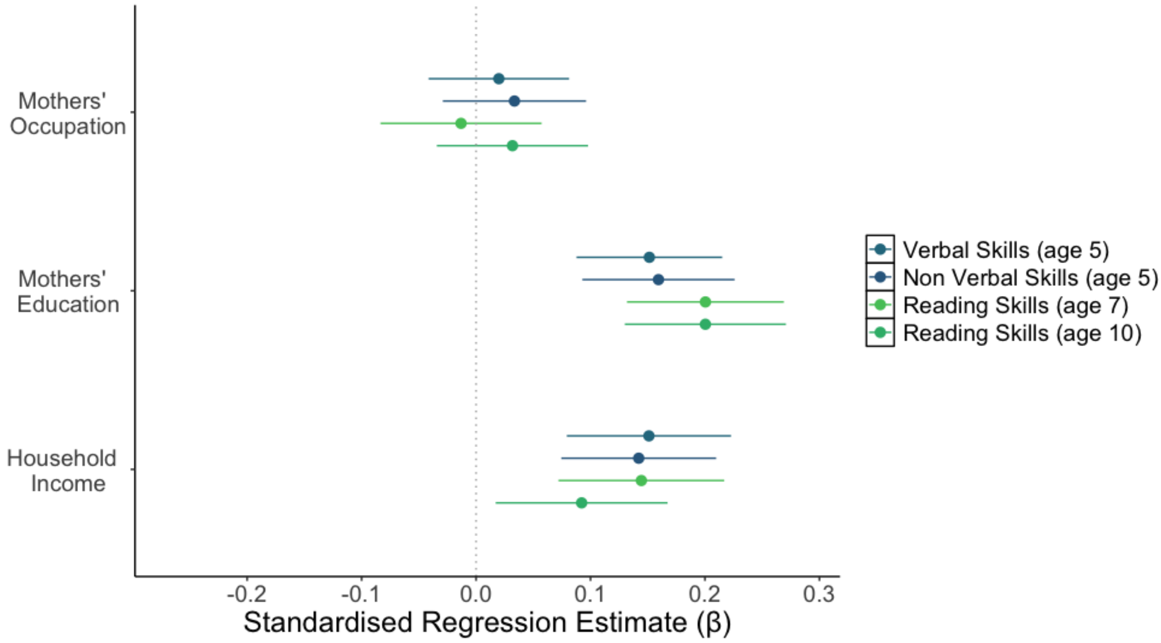

Figure 12: Predicting children's cognition and literacy from mothers' SES.

Note: N= 894 families. Dots represent standardised (beta) regression estimates, and lines represent 95% confidence intervals. All models were adjusted for mothers' age. Figure adapted from Brown et al. (2024).

We then compared mothers' SES and speech as predictors of children's cognition and literacy in the same model (Figure 13). In this model, associations between mothers' vocabulary sophistication and children's cognitive and literacy outcomes were reduced. Specifically, the associations between mothers' vocabulary sophistication and children's verbal, non-verbal and reading skills halved in effect size (i.e., they decreased to 1-2%), but they remained significant. The effect sizes of the predictions from mothers' education and income for children's cognition and literacy did not change in the models that also included mothers' vocabulary sophistication. These findings suggest that the effect of mothers' SES on children's cognitive and literacy abilities is likely more pervasive than that of mothers' vocabulary sophistication. We observed no differences in the associations between mothers' lexical diversity and grammatical complexity with children's cognition and literacy, which were non-significant before and after adding mothers' SES to the models.

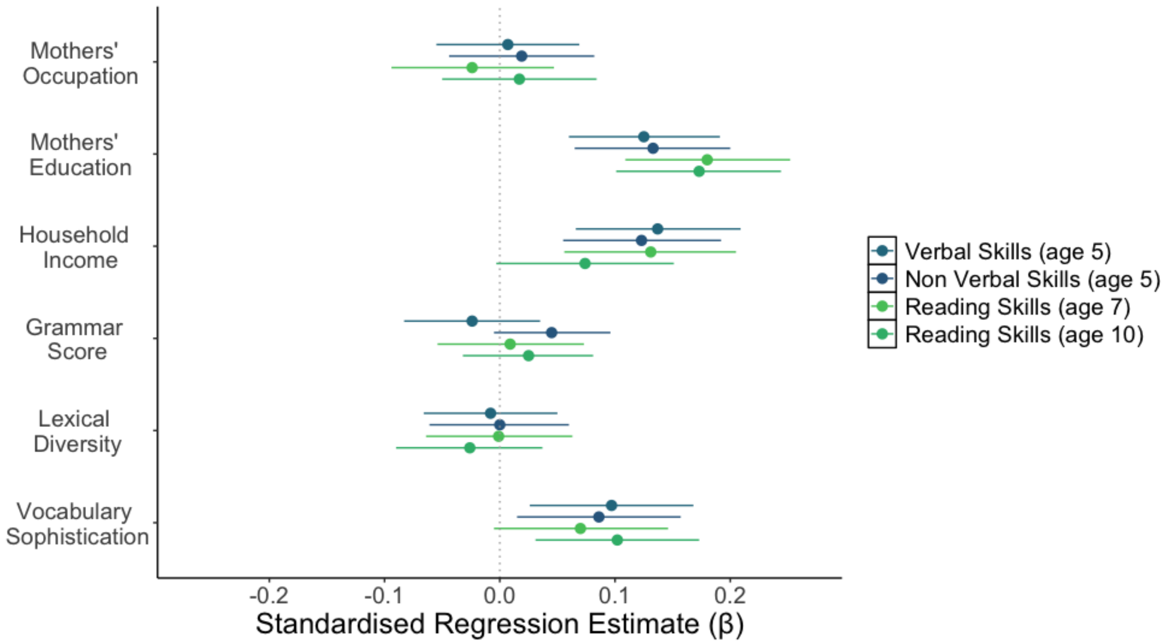

Figure 13: Predicting children's cognition and literacy from mothers' SES and speech

Note: N= 894 Families, dots represent standardised (beta) regression estimates, and lines represent 95% confidence intervals. All models were adjusted for mothers' age. Figure adapted from Brown et al. (2025).

Research Question 2b: Does mothers' speech predict their children's educational achievement?

We next tested the relationship between mothers' speech and children's educational achievement, as rated by teachers at ages 7, 10 and 12 years. Mothers' vocabulary sophistication was significantly associated with children's stable differences in educational achievement (intercept), accounting for 2% of the variance, but not with improvement and decreases in educational achievement over time (slope). Thus, mothers' vocabulary sophistication predicted children's achievement differences that persisted throughout school with a small effect size but did not forecast children's improvements or worsening in school performance over time relative to where they started. Mothers' lexical diversity and grammatical complexity were associated neither with the intercept nor the slope of children's educational achievement. Akin to our findings on children's cognition and literacy, these results suggest that mothers' vocabulary sophistication predicts children's differences in educational achievement. That is, mothers who use more sophisticated vocabulary in their speech may help their children to achieve an advantage in educational achievement that is stable from age 7 through 12 years. Yet, mothers' vocabulary sophistication did not appear to influence whether children's school performance improves or declines over time relative to their starting point.

We then tested the relationship between mothers' SES and children's educational achievement. Mothers' educational attainment and household income, respectively, accounted for 9% and 14% of children's stable differences in educational achievement (intercept). This effect was larger than the association that we observed between mothers' vocabulary sophistication and children's stable differences in educational achievement (i.e., 2% versus 9-14%). Mothers' SES indicators were not associated with changes in achievement (slope) across the school years, akin to mothers' vocabulary sophistication. Mothers' occupation was not significantly associated with the intercept and the slope. Overall, children whose mothers reported higher educational qualifications or greater household income tended to perform better in school between the ages of 7 and 12 years. Yet, mothers' education and income did not influence whether children improved or declined in their school performance relative to this starting point.

Next, we tested the extent to which associations between mothers' vocabulary sophistication and children's educational achievement (intercept) could be attributed to mothers' SES (see Figure 14). Associations between mothers' vocabulary sophistication and children's educational achievement became non-significant after including mothers' SES in our models. This finding suggested that the link between mothers' vocabulary sophistication and children's educational achievement could be primarily explained by the mothers' SES. In other words, the advantage in children's educational achievement that was associated with mothers' vocabulary sophistication likely reflects the broader influence of mothers' SES. Overall, mothers' SES appeared to exert greater pervasive, long-term influence on children's education-related outcomes than mothers' speech in our analyses so far. That said, mothers' vocabulary sophistication emerged as a significant correlate of mothers SES, as well as a significant predictor of children's cognition and literacy, even after taking the influence of mothers' SES into account. It therefore seems that mothers' vocabulary sophistication likely plays an important role, even if its relative effect size is modest.

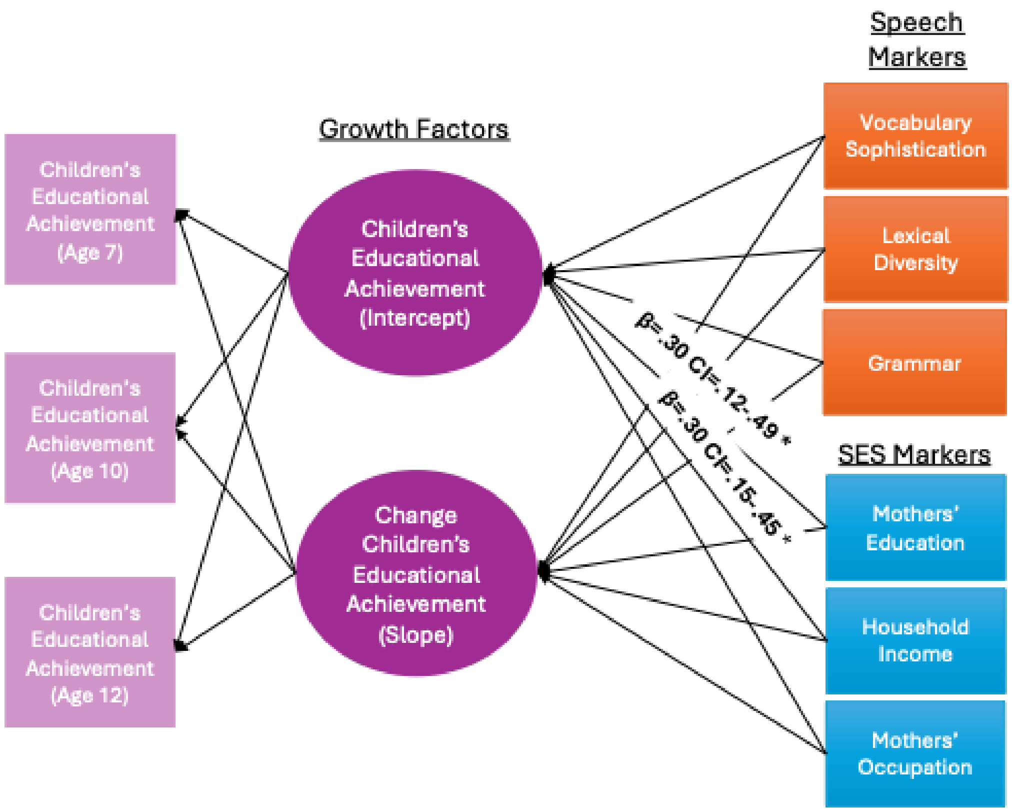

Figure 14: Predicting children's differences in educational achievement from mothers' SES and speech

Note: This is the latent growth factor model shown in Figure 7, now updated with path estimates. Only significant (p<.05) regression paths' beta estimates are shown with 95% Confidence Intervals; factor loadings and non-significant regression weights were omitted to sustain graphical clarity.

Research Question 3: Does mothers' speech mediate the association between family background and education-related outcomes?

We fitted mediation models for children's cognitive and literacy abilities and educational achievement. Mothers' education and household income significantly predicted education-related outcomes and, thus, were included as predictors in the mediation models. Mothers' vocabulary sophistication was included as a mediator because it was significantly associated with mothers' education, household income, and children's education-related outcomes, including cognition, literacy, and stable differences in educational achievement (intercept). We tested simultaneously whether vocabulary sophistication mediated the association between mothers' education and household income with children's education-related outcomes in the same model (Figure 15).

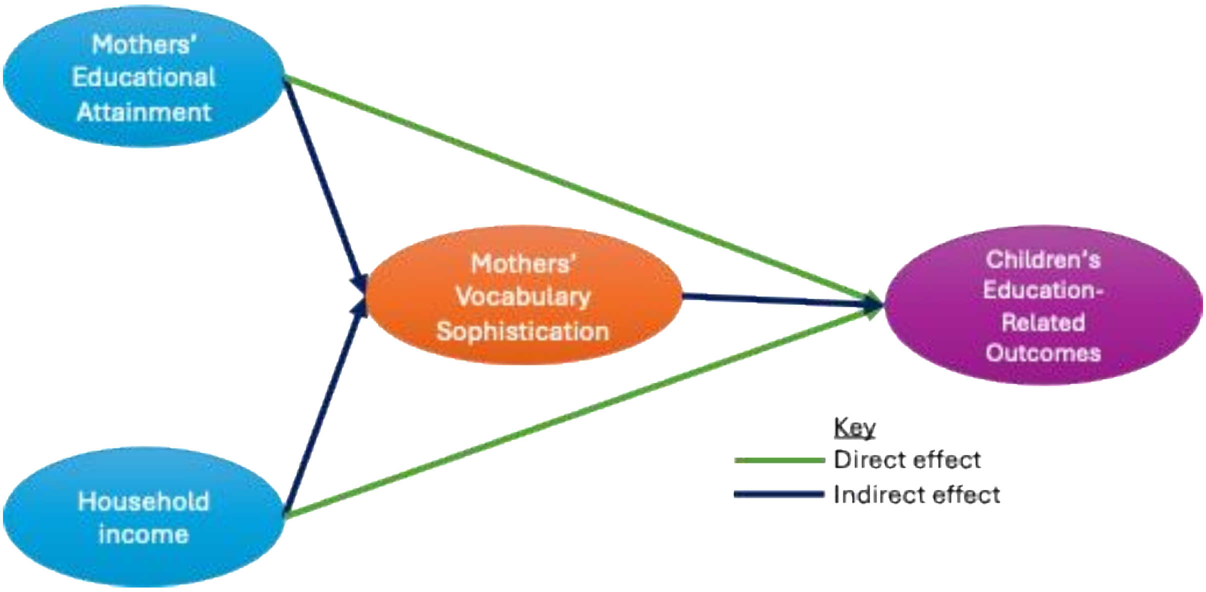

Figure 15: Mothers' vocabulary sophistication as a mediator between mothers' SES and children's education-related outcomes

Note: This model shows the mediation of the associations between mothers' education and household income by mothers' vocabulary sophistication onto children's education-related outcomes. Separate models were tested for each education-related outcome: verbal skills at age 5; non-verbal skills at age 5; reading skills at age 7 and age 10; educational achievement from age 7 through to 12 (i.e., 5 models in total).

Mothers' vocabulary sophistication significantly mediated the association between mothers' educational attainment and children's verbal and non-verbal skills at age 5 years, as well as their literacy skills at age 10 years (Figure 16). At age 7, the mediation for literacy skills was not significant (Figure 16). Mothers' vocabulary sophistication significantly mediated the association between household income and children's verbal and non-verbal skills at age 5 years, and their literacy skills at age 10 years, but not at age 7 years (Figure 16). We observed no significant mediation for stable educational achievement (Figure 16).

Effect sizes for the significant mediations were small, ranging from 13% to 24% of the associations between SES and children's cognition and literacy, with models accounting for 11% to 8% of the variance. In absolute terms, mothers' vocabulary sophistication explained a small proportion of the differences in children's outcomes, between 1% and 3%. Although these effects are modest, they may still be meaningful at the population level, where small influences can accumulate across development. In sum, these results suggest that mothers' vocabulary sophistication partly explains the associations between mothers' educational attainment and household income with children's cognition and literacy, but this contribution is limited in size and not consistently observed across all ages and outcomes.

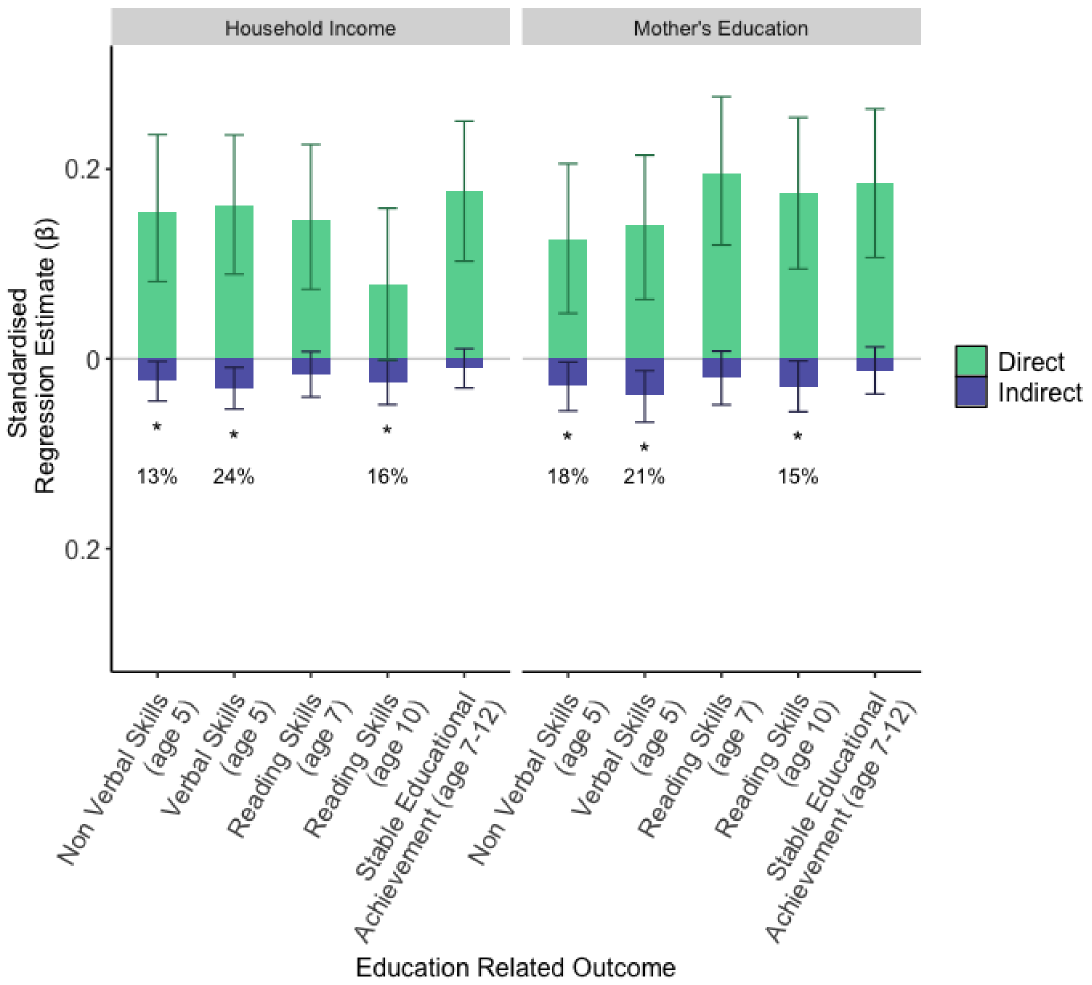

Figure 16: Direct and indirect (mediated via mothers' vocabulary sophistication) influences on children's education-related outcomes

Note: Green bars represent direct effect (SES indicator to education-related outcome), blue bars represent the indirect effect (mediated via mothers' speech). The percentage below each bar indicates how much of total effect is explained by the indirect effect (i.e., 100% would be full mediation). Figure adapted from Brown et al. (2025).

Throughout our analyses, mothers' vocabulary sophistication predicted children's cognition and literacy more strongly than children's educational achievement. Children of mothers with more sophisticated vocabulary tended to have greater cognition and literacy, even after accounting for SES indicators like the mothers' education levels and household income. We also found that mothers' vocabulary sophistication helped explain (or mediate) part of the link between their SES indicators (education and household income) and their children's cognition and literacy skills. Such mediation was not observed for children's educational achievement. That is, mothers' vocabulary sophistication neither directly influenced educational achievement nor did it explain (i.e., mediated) the link between mothers' education and income and children's educational achievement. Together, these findings suggest that mothers' vocabulary sophistication may play a different role in children's development of cognition and literacy as compared to their educational achievement.

Cognition and literacy are comparatively narrow learning skills that precede educational achievement (Dickinson et al., 2010; Magalhães et al., 2020). Educational achievement is a broader construct that encompasses many factors, such as school attendance, study habits, and classroom behaviour (Gottfried, 2010; Ratcliff et al., 2016). Thus, mothers' vocabulary sophistication may have direct benefits for the development of cognition and literacy (Beck et al., 2013; Dickinson et al., 2010; Oslund et al., 2016), which we observed here, but its influences on educational achievement could be more indirect (Vadivel et al., 2023). For example, exposure to sophisticated vocabulary likely contributes directly to literacy by improving how quickly and effectively children can read and understand complex texts (Weizman & Snow, 2001). Becoming exposed to sophisticated vocabulary may also benefit cognitive development more broadly beyond literacy, for example because encountering high-quality speech helps children develop critical thinking and problem-solving abilities (Mahurin et al., 2021; Shavlik et al., 2021). Over time, these benefits for literacy and cognition and literacy may translate into advantages in educational achievement. Future research that employs precise measures and repeated assessments of learning skills and educational achievement are needed to empirically test these predictions.

Research Question 4: To what extent is the role of mothers' speech in the transmission of family background inequality in education influenced by genetics?

To address this question, we focused on the role that mothers' vocabulary sophistication plays in the association between mothers' and children's educational attainment. This focus resulted from our findings above, which overall suggested that vocabulary sophistication is the most likely marker of mothers' speech that plays a role in the intergenerational transmission of education. We used mothers' and children's highest educational qualifications to index the strength of family background inequality in education, rather than measures of learning skills or educational achievement, because these were only recorded for children, not for mothers.

We first estimated the 'word gap' in our sample (Figure 17). These analyses supplement our findings reported above (research question 1). Differences in mothers' educational attainment correlated with their differences in vocabulary sophistication r =.46. (Note that this is the raw correlation estimate and therefore not directly comparable to the regression estimates reported in Figure 10.) Mothers without educational qualifications used 14.0% of sophisticated vocabulary in their speech, on average. By comparison, mothers who had obtained a postgraduate degree used on average 20.7% of sophisticated vocabulary in their speech. This discrepancy means that mothers with the highest educational qualifications used on average a third more sophisticated vocabulary in their speech than mothers who reported no educational qualifications.

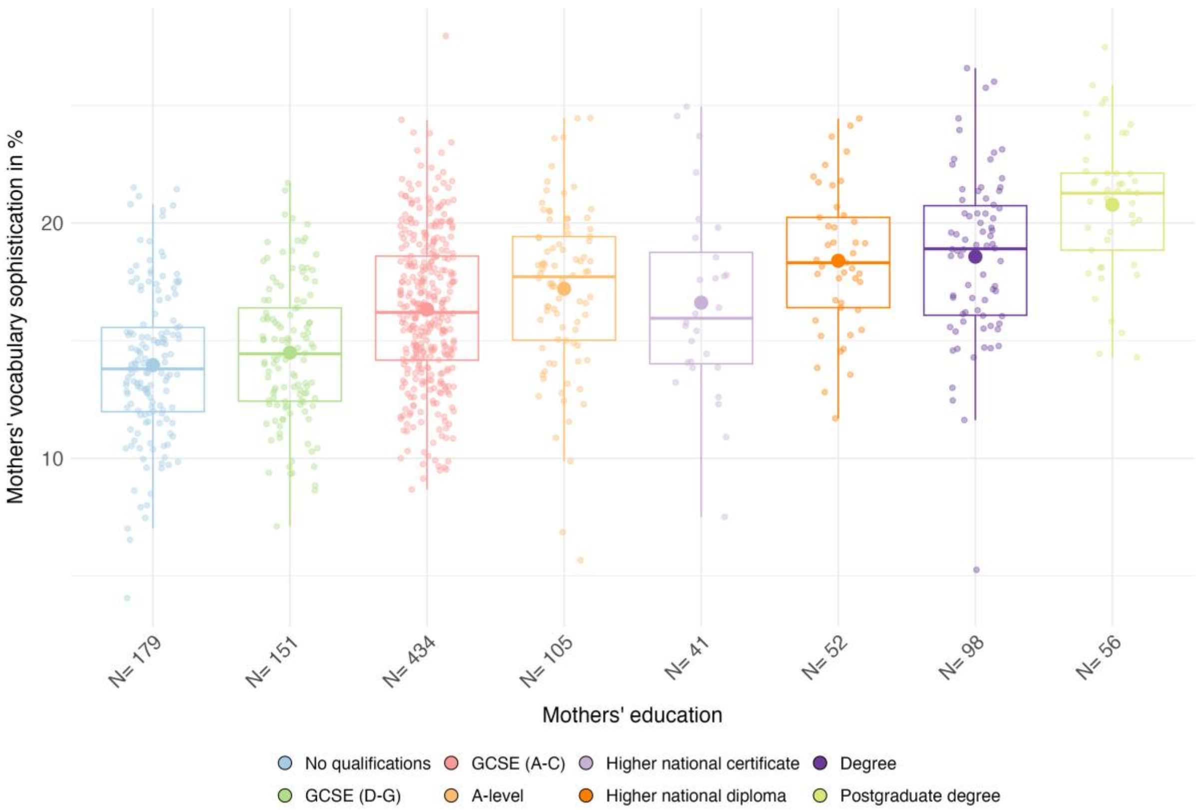

Figure 17: The 'word gap' in mothers' vocabulary sophistication

Note. Boxes represent the interquartile range (IQR); the horizontal lines indicate medians; filled circles indicate means. Individual data points are overlaid with jitter. N = number of mothers per educational level. GCSE (General Certificate of Secondary Education) and A-level refer to secondary school leaving qualifications. D-G reflect grades and denote basic skills; A-C are awarded for advanced skills. Higher national certificate includes college level qualifications. Mothers' highest educational qualification was assessed at mean age 34 years. Children's highest educational qualification was assessed at age 18 years.

As expected, both mothers' and children's educational attainment were genetically influenced. Children's polygenic scores accounted for 8% of the variance in their educational attainment. Mothers' polygenic scores explained 7% of the variance in their educational attainment and 5% of the variance in their vocabulary. These findings confirmed our principal hypotheses that polygenic scores significantly predict educational attainment and vocabulary in our sample.

We used path models to discern environmental from genetic influences in the association between mothers' speech and children's education-related outcomes (see Figure 9 above and top panel Figure 18 below). The bottom panel of Figure 18 illustrates the results from our path models. Mothers' educational attainment predicted children's educational attainment at age 18, with the model that also included mothers' age as a covariate accounting for 14% of the variance. This effect size reflects the strength of family background inequality in education in our sample (i.e., per Standard Deviation increase in mothers' education, children's education increases by 20%). In the environmental transmission model (i), we added mothers' vocabulary sophistication as a mediator. Mothers' vocabulary mediated 16% (paths b*c) of the association between mothers' and children's educational attainment. Accordingly, the direct effect of mothers' education on children's education (path a) reduced relative to a baseline model (not shown).

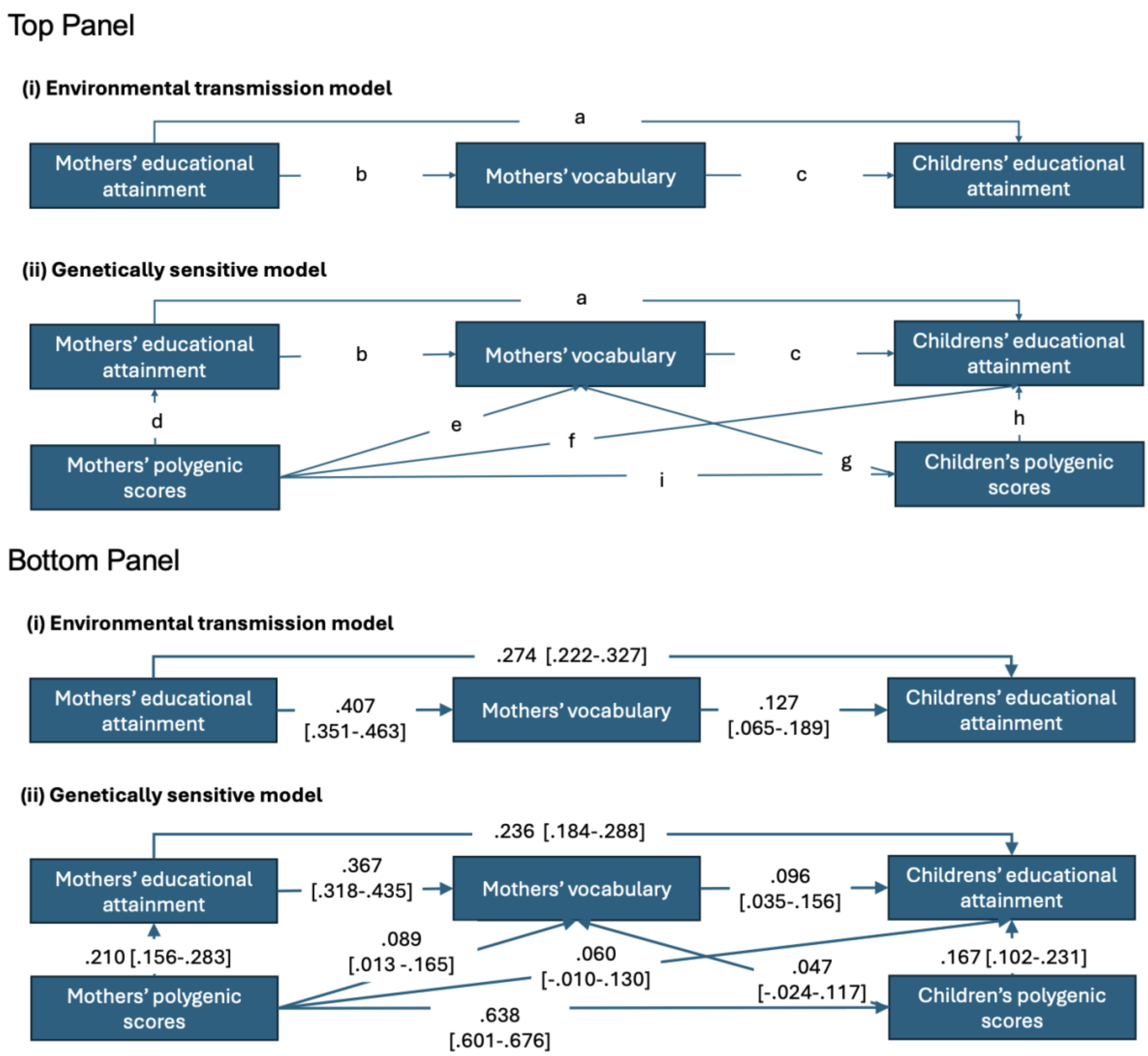

Figure 18: Path model results of the educational attainment transmission from mothers to children

Note. The top panel shows the conceptual models; the bottom panel shows the estimated path weights. CI 95% are shown in []. All models were corrected for mothers' age (in years). Figure adapted from von Stumm et al. (2026)

The genetically sensitive model (ii) included mothers' and children's polygenic scores and accounted for 19% of the variance in children's educational attainment (Figure 18 bottom panel). The direct effect (path a) of mothers' educational attainment on children's educational attainment was reduced by 14% relative to the environmental transmission model (i). This finding suggests that family background inequality in education remains substantial even after taking mothers' and children's genetic propensities, as measured by polygenic scores, into account. The effect of mothers' vocabulary as a mediator of the educational attainment transmission was lower by a third in model (ii) relative to model (i) (paths b*c). This reduction reflects the degree of genetic confounding (i.e., the influence of the genetic variants that mothers and children share on the educational attainment transmission via mothers' vocabulary). Overall, we estimated that 17% of the educational attainment transmission from mothers to children could be attributed to genetic confounding (comparing paths a+b*c from model (i) to model (ii)).

There was evidence for genetic nurture, as indicated by a significant path from mothers' polygenic scores onto children's educational attainment via mothers' educational attainment (paths d*a) and via mothers' educational attainment and their vocabulary (paths d*b*c) Genetic nurture effects that were mediated via mothers' vocabulary alone were not significant, as were the genetic nurture effects mediated by environments not further specified (path f). These null findings suggest that mothers' vocabulary does not operate as an independent pathway of genetic nurture, but rather in conjunction with broader socioeconomic factors such as education. Indeed, genetic nurture effects that were mediated by mothers' educational attainment (paths d*a) and by mothers' educational attainment and vocabulary (paths d*b*c) were significant. These genetic nurture effects accounted for 26% of the influences from mothers' polygenic scores onto children's educational attainment (i.e., paths d*a+d*b*c+e*c+f+i*h). We note that mothers' vocabulary was a significant environmental mediator of genetic nurture only in conjunction with mothers' education, but not independently.

To summarize the degree to which genetic and environmental paths contribute to the mother-child transmission of education (i.e., genetic confounding, genetic transmission, genetic nurture, and nurture; Figure 19), we combined standardized pathway estimates across models. Nurture (paths a + b*c), which was independent of genetic influences, explained 54% of the transmission of educational attainment from mothers to children. Of this nurture effect, 13% were due to mothers' vocabulary. By comparison, genetic nurture effects via mothers' education and via mothers' education and vocabulary accounted for 14% of the educational attainment transmission, of which 24% were mediated by mothers' vocabulary. With reference to the model's variance (R^2 = .189), these findings suggested that mothers' vocabulary accounted for approximately 3% of the transmission of educational attainment independent of genetic transmission and genetic confounding via nurture and genetic nurture pathways, respectively.
Although these effects are small in magnitude, they may still be meaningful at the population level, where small influences can accumulate over time. Overall, these findings provide cautious support for a limited causal role of mothers' vocabulary in the intergenerational transmission of educational attainment.

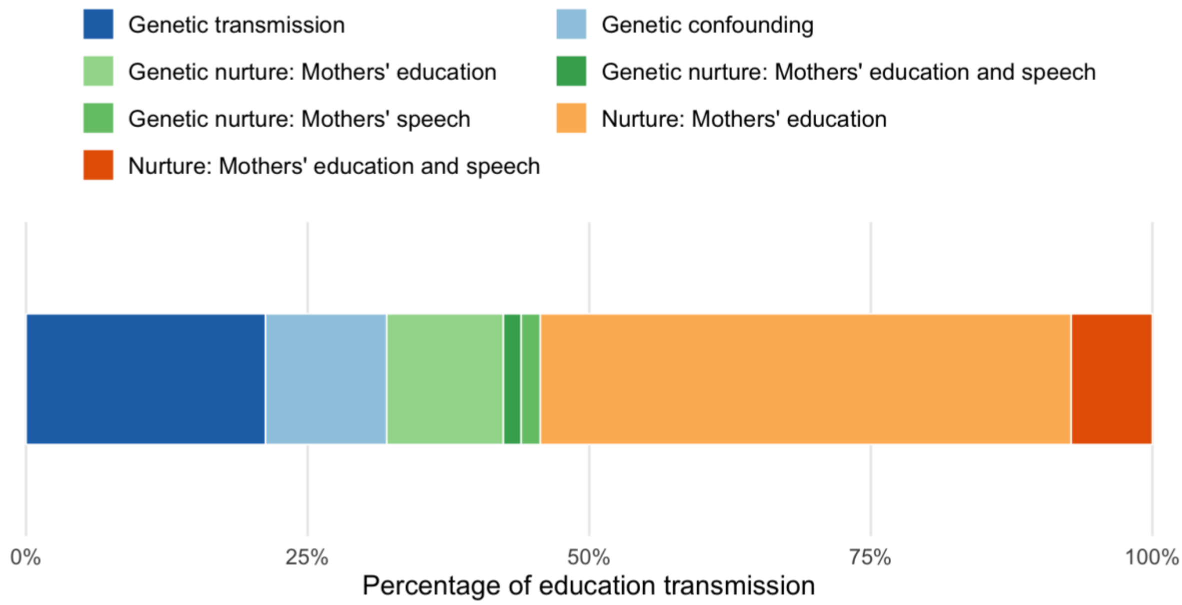

Figure 19: Transmission pathways of educational attainment from mothers to children

Note. Path estimates were based on standardised coefficients from model (i) (Figure 18) that were rescaled to estimate percentage contributions, after including genetic confounding effects (i.e., comparing paths a + b*c across models (i) and (ii)). Nurture and genetic nurture effects are independent of genetic transmission, inferred from polygenic scores, and index likely causal influences (orange and green colours). Paths that involve genetic transmission (shades of blue) include genetic confounding and genetic transmission. Figure adapted from von Stumm et al. (2026).

In summary, our genetically sensitive path models suggested that mothers' vocabulary sophistication may have causal influences on the association between mothers' and children's educational attainment. However, corresponding effect sizes were small, suggesting that interventions that target mothers' vocabulary sophistication to improve children's educational outcomes are likely to achieve only modest change.

Limitations

Our research has many strengths, including rich observational data across a 13-year follow-up period from a large family cohort study whose population is representative of Britain's socioeconomic conditions. These rich and unique data allowed estimating the association between mothers' speech and children's education-related outcomes after controlling for genetic confounding, which is a major threat to interpreting parent-child associations in observational data. Furthermore, our study is the first to quantify speech from naturalistic samples in a large, population representative cohort. However, we also acknowledge that there are limitations to our studies, the most important of which we discuss below.

Diversity of children's early life language environments

The findings from this project confirm the hypothesis that mothers' speech significantly influences children's differences in education-related outcomes during the years of formal education. However, the corresponding effect sizes were very small, which posits a challenge for intervention efforts that target mothers' speech to improve children's educational success. Yet, it is important to acknowledge here that our measures of mothers' speech only captured some aspects of speech and that even these aspects were not assessed in child-directed contexts. In addition, we did not have data on the speech that children are exposed to from other sources, including from fathers and other caregivers, from other children, and from electronic sources, or their broader aspects of the language environments (e.g., mothers' responsiveness; Wade et al., 2018).

Another issue is that the recordings of mothers' speech that we analysed here may not reflect the speech children experienced before they started formal schooling. Child-directed speech, a unique speech style that is typical pre-school, is likely pivotal for children's language acquisition during the early years (Rowe, 2008, 2018). Yet, E-Risk has collected no measures of mothers' child-directed speech. Therefore, we could not compare the lexical and grammatical complexity between mothers' child- and their adult-directed speech (e.g., Hoff, 2003; Hoff-Ginsberg, 1991; Rowe, 2012). We may not have observed a relationship between adult-directed speech and children's later education-related outcomes because the speech directed at children before they start school sets the trajectory of learning. Likewise, child-directed speech may vary to a greater extent than adult-directed speech as a function of mothers' SES (Dailey & Bergelson, 2022). Few studies have compared the influence of child-directed versus adult-directed speech on children's language development (cf., Kempe et al., 2024), and no prior research explored their role for children's long-term education-related outcomes. Future studies must close this gap, because longitudinal evidence on the influence of mothers' speech is critical for intervening effectively to improve children's educational success.

Our analyses allow some conclusions about the role of mothers' speech in the transmission of family background inequality in education but not about other caregivers' speech. Most notably, no data were available on the speech of fathers. In general, research on child development tends to focus on mothers' rather than on fathers' speech. In cases where fathers' speech is a research focus, it is frequently compared to mothers' speech (Pancsofar, 2020). In those studies, similar findings emerge for the quantity of fathers' speech as has been reported for mothers' speech: The greater the amount of speech that children hear from their fathers, the more advanced is their language development (Schwab et al., 2018). However, the speech that fathers direct at their children differs from that of mothers in vocabulary and grammar. On average, fathers' vocabulary tends to be more complex and varied than mothers' (Pancsofar & Vernon-Feagans, 2006), and fathers' speech also contains more wh-questions and requests for clarifications that elicit complex speech from their children (Rowe et al., 2004). These findings suggests that fathers' speech may have distinct effects from mothers' speech on children's language development. Fathers' speech may even play a more significant role than mothers' speech for children's development during the years of formal education, because of its comparatively high complexity (Pancsofar, 2020; Shapiro et al., 2021). That said, few studies on child development explored fathers' speech and thus, hypotheses about the influence of fathers' speech are largely speculative.

Our research could not broadly consider children's language environment. We therefore call for future studies study language environments beyond mothers' speech in childhood and adolescence. During the years of formal schooling, peers and teachers assume prominent roles for children's language environments, alongside the influence mothers and fathers (Barnes & Dickinson, 2017; Chen et al., 2020; Dickinson & Porche, 2011). Some studies have shown that children's language development is associated with the speech that teachers use. For example, children in classrooms where teachers use more sophisticated vocabulary show higher vocabulary skills at the end of the school year than children in classrooms whose teachers used simpler vocabulary (Dickinson & Porche, 2011). Overall, however, the evidence regarding teachers' contributions to language development is both mixed and limited. For example, targeting teacher's speech to improve the language environments that children experience in the classroom can increase children's expressive language but has little effect on their understanding and learning (Abel et al., 2015).

Besides parents and teachers, peer interactions are core pillars of children's language environments. Prior research suggested that children interact most often with other children whose language development resembles theirs (Justice et al., 2011). In other words, children with stronger language skills tend to associate with high-language ability peers, who then jointly co-produce language environments that benefit language development (Justice et al., 2011). By comparison, children with weaker language skills tend to interact more often with peers who have similarly limited language abilities, thereby inadvertently creating fewer opportunities to access rich linguistic resources (Chen et al., 2020). We could study the influence of peers' language and related mechanisms here because such data were not available. Future research is needed to establish whether the influence of mothers' speech on children's education-related outcomes reduces across the school years relative to the influence from other speech sources, such as peer interactions.

Inferring causality from observational data

Findings on genetic confounding and genetic nurture must be interpreted in light of several limitations. First, controlling for genetic confounding using polygenic scores is an imperfect method, because polygenic scores do not capture all genetic influences on traits and behaviours. A common finding in studies that estimate heritability using DNA is that estimates of heritability are lower than those derived from twin and adoption studies. This discrepancy in estimates is known as the 'missing heritability' or the 'heritability gap' (Manolio et al., 2009). There are multiple possible reasons that may explain why DNA-based heritability estimates are lower than those from twin studies. For example, DNA-based heritability estimates consider common genetic differences but not relatively rare genetic variants, which are thought to contribute to heritability (Wainschtein et al., 2025; Young, 2019). If DNA-based methods, such as polygenic scores, underestimate the true heritability of a trait or behaviour, it means that they also underestimate the extent of genetic confounding when used as control variables. The bottom line is that even after controlling for polygenic scores, associations between parenting and child outcomes may not fully reflect environmental, causal associations. There may be some residual confounding that this method does not pick up on.

Second, some concerns have recently been raised in the literature about findings of genetic nurture. In particular, genetic nurture effects are sensitive to a type of bias called 'population stratification' (Nivard et al., 2022). Population stratification is a concept in genetics and epidemiology that refers to the presence of systematic differences in the genetic makeup of subgroups within a larger population. These subgroups can exist due to various reasons, such as geographic separation, cultural practices, or historical migration patterns. Researchers typically account for population stratification in their analyses, but it can still create bias and potentially lead to overestimation of genetic nurture effects.

Third, the research design in the current project – even though it includes genetic information – is still an observational research design. Thus, it reveals 'what is' and not 'what could be'. However, when based on rich, longitudinal datasets that make it possible to control for a variety of potential confounders, including genetic ones, studies like ours allow making an educated guess about the potential impact of interventions on child outcomes. This can then be followed up and tested in more applied research, such as randomised-controlled trials, that formally test the impact of an intervention, such as parent training.

With these limitations in mind, findings of genetic confounding and genetic nurture have several implications. First, if an association between an environmental variable and a child outcome is confounded by genetics, changes in that environmental variable would not necessarily change the outcome in a causal fashion. For example, to the extent that the association between mothers' speech and children's educational achievement is due to genetic confounding, interventions that target mothers' speech may not necessarily have an impact on school grades. Second, to the extent that an association between an environmental variable and a child outcome remains even after controlling for genetic confounding, an intervention targeting that environmental variable would be able to change the child outcome. Third, if parent genes influence children's development not only via passing on genes to their children, but also via the environments that they create for their children, then these environments themselves can be modified through interventions. This phenomenon – when parents' genes influence children's environments independent of the genes that parents and children share – is called genetic nurture. Genetic nurture effects implied environments that can be modified, for example such as early childhood home visiting programs and or parenting interventions. Thus, a finding of genetic nurture would suggest that it is possible to intervene in the path from genes to behaviour. In our analyses, we observed genetic nurture effects in the way that mothers' genes influenced children's education-related outcomes via their own education and vocabulary sophistication. The effect sizes of this path were very small, suggesting that interventions that target this environmental pathway are unlikely to produce substantial changes in children.

Differences in twins' and singletons' language development

Our data came from a family cohort who had twin rather than singleton births. A potential challenge to interpreting our findings is that twins may develop differently than singletons and thus, our results may not generalise across families. Indeed, a research review concluded that twins' language development was on average delayed by 2 to 8 months behind singletons, if given as a time difference between twins and singletons reaching the same language development milestones (Thorpe, 2006). This twin-singleton delay in language has been found to persist until the age of 10 years, when differences between twins' and singletons' language ability tend to become non-significant (Webbink et al., 2008). The existence of differences in twins' and singletons' language development could imply that findings from language development research that use twin samples may not be generalisable to singleton populations. To address the comparability of twins and singletons in the language development, we conducted additional analyses in a sample of twins and their younger singleton siblings from the Twins Early Development Study (TEDS; Lockhart et al., 2023).

Research design

Existing research on twin-singleton differences in development have often utilised samples of genetically unrelated twins and singletons (i.e., singletons from different families than twins and vice versa). This approach makes it impossible to account for family-level confounding in the prediction of language development, such as differences in SES, the wider home environment, and genetics. By testing twins and singletons from the same families, family-level confounding can be accounted for.

TEDS is a UK-representative cohort of twins born in England and Wales from 1994 to 1996[2] (Lockhart et al., 2023). A subsample of TEDS included 851 twin families with a younger singleton sibling, which we capitalised on to conduct within-families comparisons between twins and singletons. The twins and their younger siblings completed tests of language ability when they were ages 2, 3, 4, and 7 years old (i.e., all children were assessed at the same chronological ages, respectively, but twins and singletons were assessed at different times or dates). The language measures at ages 2, 3, and 4 years were adapted from the MCDI (MacArthur-Bates Communicative Development Inventories; Fenson et al., 1994), and consisted of tests of vocabulary and grammar, which were designed for parents to answer on behalf of their children. At age 7, vocabulary, verbal concept formation, and verbal abstract reasoning were tested using items from the WISC vocabulary and similarities tests (Wechsler Intelligence Scale for Children; Wechsler, 1949) adapted for administration via telephone.

Findings

We found that being a twin versus a singleton was significantly associated with language development. Singletons outperformed twins' language ability at ages 2, 3, and 4 years (d ranged from 0.12 to 0.41, p ranged from .002 to <.001), with the biggest effect size at age 2,

[2] E-Risk was drawn from TEDS. Both cohorts have been led by overlapping yet distinct different research teams since 1999, with both cohorts undergoing different assessments at different ages.

and the difference between twins' and singletons' language scores decreasing with age. By age 7 years, twins had caught up with and exceeded singletons' abilities (*d*= -0.35, *p*= <.001; see Figure 18). To summarise, small to moderate differences in twins' and singletons' language development were observed in the early years prior to starting formal schooling. These differences diminished over time and could be no longer observed after children had started primary school.

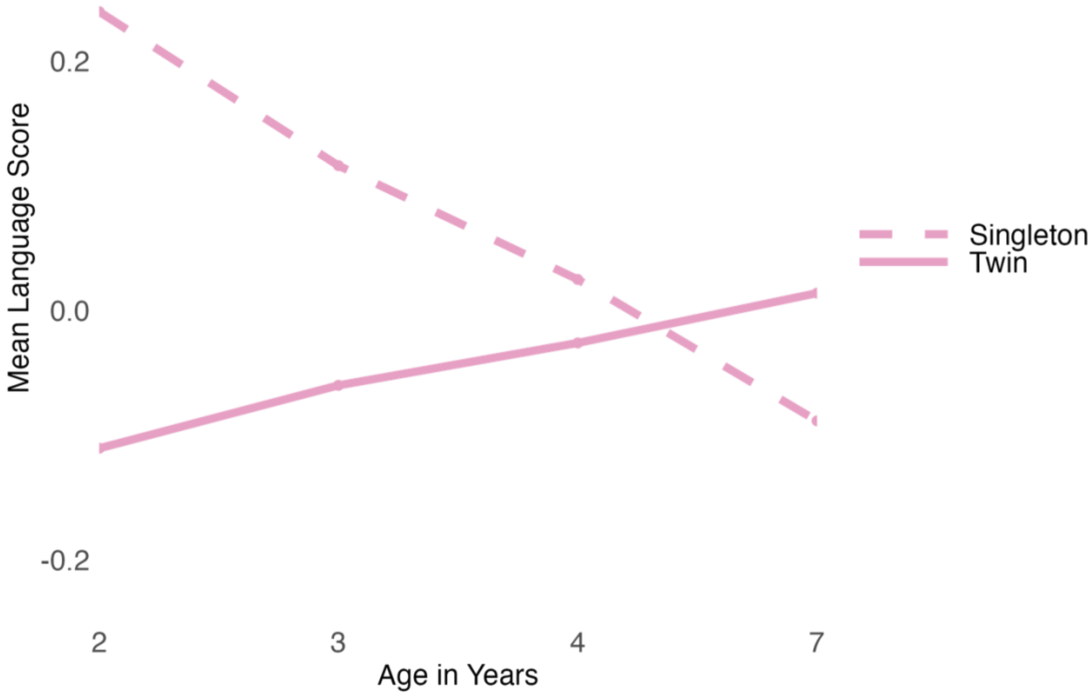

Figure 20: Mean differences in twins' and singletons' language ability from age 2 through to 7 years

Note. Average language scores are plotted across ages for twins and singletons. Figure adapted from Wood et al. (2026).

We found that twins' language development is delayed when compared to singletons at ages 2, 3, and 4 years. These findings suggest that twins' language development experiences may not be generalisable to singletons' during their early years. In the present research, we analysed children's language abilities from age 5 to 18 years – ages when twins' and singletons' differences at the group level (i.e., sibling type) would have diminished. However, our findings caution somewhat that it may not be recommendable to use twin samples for exploring language development during the early years, when findings may not be generalisable to singleton populations. Overall, we concluded that twin-singleton differences in language development neither invalidate the current findings nor do they advise against analysing data from twin cohorts to address research questions like ours.

Implications and Recommendations for Research Stakeholders

We studied here the role of mothers' speech in the transmission of family background inequality in education. Our results offer insight into 'what is' rather than 'what could be'. No direct implications for research, practice, or policy follow, although we can formulate some recommendations based on our findings. For example, our findings may inform the theoretical background of future applied research in this area. Below, we briefly outline potential directions four stakeholder groups for whom our findings are likely relevant: Researchers, policymakers, educators, and families. Given the preliminary nature of our findings and our call for additional research in this area, we describe more implications for researchers, who are the most direct beneficiaries of this research, than for policymakers, educators, and families. To aid navigation, we highlight throughout which implications are most relevant for each group and what practical conclusions they may draw from the findings.

For researchers: Implications for future research

We explored the role of mothers' speech for children's education-related outcomes beyond the early years and independent of family-level confounding (e.g., SES and genetics). Our findings revealed three significant gaps in the previous literature that researchers should address in the future.

The first pertains to the differences and similarities of mothers' child- and adult-directed speech. We quantified mothers' speech from transcripts of interviews that they gave to trained health researchers (i.e., adults); thus, mothers' speech in the context of our research was adult-directed. Prior research has shown that mothers' child-directed speech predicts children's language ability during the early years (Huttenlocher et al., 2002; Rowe, 2012) and aids their education-related outcomes in primary school (Durham et al., 2007; Pace et al., 2019). However, our findings here and elsewhere (von Stumm, O'Reilly, et al., 2022) challenge the hypothesis that mothers' speech exerts significant influence on children's educational achievement after they have started formal education. One possible explanation for the discrepancy in findings is that we are analysing mothers' adult- as compared to their child-directed speech. Yet, the differences, similarities, and development of mothers' adult- and child-directed speech have not been conclusively studied to date (Kempe et al., 2024). We therefore propose that future research should investigate how the characteristics of child- and adult-directed speech differ and overlap, and if they have discernible influence on children's long-term differences in education-related outcomes.

Second, our finding that mothers' vocabulary sophistication is implied in the transmission of family background inequality in education warrants further research to explain why. We observed that mothers' vocabulary sophistication predicted children's education-related outcomes, but their grammar and lexical diversity did not. That mothers' vocabulary sophistication may play a special role for children's vocabulary development has been previously noted (Hoff & Naigles, 2002; Weizman & Snow, 2001). Furthermore, it has been argued that exposure to sophisticated vocabulary will likely benefit children's learning from academic texts, which become increasingly abstract, complex, and dense across school years (Uccelli, 2023). Thus, our findings support calls for classroom environments that teach sophisticated vocabulary on a par with the academic texts that pupils study (Bakopoulou, 2023; Cabral-Gouveia et al., 2023). That said, the exact pathways and mechanisms through which mothers' vocabulary sophistication may inform children's developmental differences in education-related outcomes are, to date, unknown (Schleppegrell, 2001; Uccelli, 2023).

Our third suggestion is broadening the focus of research on the transmission of family background inequality to consider alternative explanatory pathways beyond mothers' speech. Previous research's narrow emphasis (Sperry et al., 2019) on the role of mothers' speech may have led inadvertently to neglecting alternative linguistic and non-linguistic pathways that likely carry equal, if not greater, explanatory power (Caro et al., 2009; Dolean et al., 2019; Hart et al., 2013; Hoff, 2013). Intervention efforts based on today's limited knowledge of the transmission pathways of family background inequality risk attributing too much responsibility to mothers' speech for children's educational successes and failures. Such misattributions can reinforce narratives that mothers, rather than the social and economic conditions in which they raise their children, are the root of children's educational achievement differences (Adair et al., 2017; Patel et al., 2023; Sperry et al., 2019). The research literature would benefit from investigating non-linguistic pathways, such as socioeconomic factors, and alternative linguistic pathways such as the speech of other caregivers and peers in the classroom. By doing so, intervention efforts can be diversified and consider on a broader range of explanatory pathways, thereby avoiding attributing undue responsibility or blame to mothers.

For policymakers: Implications for policy design

For policymakers, the key question is whether mothers' speech represents an effective and scalable target for reducing educational inequality. In this context, children's early environments have long been a focus of policymakers. For example, the Supporting Families programme has been implemented by the UK government since 2015[3], offering targeted support to vulnerable families to improve their home environment. At the core of the programme, keyworkers provide support to families with parenting, debt and housing needs, and getting children to school (Ministry of Housing, Communities & Local Government, 2021). Our research offers some insights on mothers' speech as a target of policies that pertain to the family background inequality in education. Below, we discuss our perspectives on the efficacy of mothers' speech as an intervention target, according to our research findings, and highlight alternative targets for policy intervention.

We found significant effects of mothers' speech on children's education-related outcomes. However, the extent to which these were likely to be causal was very small. Specifically, about 2% of the differences in children's educational attainment were likely transmitted through mothers' speech via genetic nurture and nurture pathways, respectively. Thus, our findings imply that targeting mothers' vocabulary sophistication will improve children's education-related outcomes only to a small degree. In practical terms, this means that interventions targeting mothers' speech alone are unlikely to produce large changes in educational outcomes. That said, we caution that transmission pathways with large effect sizes are unlikely, especially within families. We argue that even the realisation of small benefits justifies the costs associated with the implementation of interventions, because their effects are likely cumulative (von Stumm, 2024; von Stumm & d'Apice, 2022). In other words, single intervention efforts, such as programmes that seek to alter mothers' vocabulary sophistication, are likely to produce modest change and may even be dismissed as costly but non-effective. Yet, when compounded with the effects of other interventions, likely with equally small individual effect sizes, substantial long-term change becomes feasible. It is also worth considering that even small differences in children's education-related outcomes can carry significant benefits across the life-course. For example, a child who, after an intervention, achieves a higher grade in a difficult subject than before may develop a sense of academic self-belief that underpins their future study efforts and work morale. That such benefits are difficult to quantify neither invalidates nor nullifies their potential influence.

Taken together, our findings suggest that policy efforts may be more impactful when they target broader socioeconomic conditions rather than focusing narrowly on parental behaviour. This underscores that policies targeting underlying socioeconomic inequalities

[3] The programme was originally introduced in 2011 and known as 'Troubled Families'.

are likely to have the broadest and most sustained impact, as these conditions shape multiple developmental pathways simultaneously. Beyond mothers' speech, we suggest policymakers prioritise the wider social inequalities that contribute to differences in children's education-related outcomes. Socioeconomic disparities relate to differences in mothers' speech as well as to other differences in home learning environment which are consequential for education-related outcomes, such as their access to learning resources and school quality (Lehrl et al., 2020; Pace et al., 2017). By addressing the root causes of these disparities, policies can likely have wide and lasting effects. Overall, our findings suggest that social and economic conditions likely play a larger role in shaping educational inequality than differences in mothers' speech alone.

For educators: Implications for classroom practice

For educators, our findings are most relevant in informing classroom-based approaches to language and learning. Educators help students to be successful at school whilst working within the cultural, social, and financial constraints of the education sector. In England, total spending per pupil fell by 9% between 2009-10 and 2019-20 (IFS, 2024), leaving little room for the implementation of interventions or additional teacher training. Spending has since increased and is set to rise even further, but the fact remains that budgets are tight in the education sector. Therefore, we discuss school-focused interventions here with the understanding that additional funding is required to facilitate their delivery in the UK education system.

Vocabulary sophistication has been argued to benefit children's learning from academic texts, which become increasingly abstract, complex, and dense across school years (Nagy & Townsend, 2012; Uccelli, 2023). Consequently, children may benefit from classroom environments that encourage exposure to sophisticated vocabulary, which aligns with the complexity of the academic texts that they study (Bakopoulou, 2023; Cabral-Gouveia et al., 2023). Interventions that increased vocabulary sophistication in the classroom have been previously found to benefit children's learning. For example, an intervention which trained preschool teachers to use instructional content (i.e., more instructive language) and rich vocabulary in the classroom improved pupils' language and maths skills (Bleses et al., 2020). Other classroom-based vocabulary interventions have been shown to improve preschool children's word learning, with effect sizes higher for higher SES than lower SES pupils (Marulis & Neuman, 2010). This suggests that schools can play an important role in supporting children's language development, particularly where home environments differ. Small effect sizes should not deter investment in interventions, as even small improvements in children's language abilities can contribute to improvements in their wider education, having a cumulative effect.

Classroom-based interventions may be more efficient and effective in reducing family background inequality in education than family-based interventions. For one, classroom-based interventions reach a larger number of children at once than is possible when targeting individual families. For the other, classroom-based interventions are typically delivered by trained education experts in environments that are safe and organised for children. By contrast, interventions that target families often put a parent in charge and take place in the family home, an environment that is more difficult to organise (e.g., there may be siblings, household chaos, etc). While budgets are limited in the UK's education sector, investments in classroom-based vocabulary interventions are likely a promising avenue for combatting family background inequality in education. Of course, classroom-based vocabulary interventions alone will be insufficient, but they are a practicable step that could be taken towards reducing family background inequality in education.

For families: Implications for everyday parenting

For families, our findings are most relevant in addressing concerns about parental responsibility for children's educational outcomes. Today's parents are held to very high standards by society, and they are under increasing pressure to create optimal conditions and environments for their children. There is no shortage of advice for parents on how to raise their children, including countless parenting books and vast social media content. The unprecedented volume of advice has been shown to decrease parents' self-esteem, to increase parenting stress, and to make parents feel insecure in their parenting role (Harries & Brown, 2019; Hudson, 2022). Our findings of small effect sizes for mothers' speech on children's educational outcomes may offer reassurance to parents who feel the pressures of parent blame. Our results suggest that, while parents' speech plays a role, it is only one of many factors influencing children's outcomes, many of which lie beyond parents' control. We hope our findings contribute toward shifting the focus from mothers' and parents' alleged responsibility for the transmission of family background inequality to recognising the influence of systemic societal factors.

We note in this context that families – by contrast to researchers, policymakers, and educators – are often the most distant beneficiaries of child development research, as it takes time for studies to be completed, published, and gain enough public attention for families to hear about the findings. For this project, we tackled this problem directly by sharing our work on public platforms that families are likely to engage with, including popular blogs and news outlets. We also ensured that our content was accessible by writing in a way that is easy for a lay audience to understand. This approach aims to ensure that research insights are accessible not only to specialists but also to families who may benefit from them.

Conclusion

Family background inequality in education is a persistent issue in the UK. Mothers' speech has been identified as a potential pathway for perpetuating family background inequality in education. We produced here robust empirical evidence that suggested that mothers' vocabulary sophistication, a marker of speech, likely has small, but causal influence on children's education-related outcomes. We also found that mothers' vocabulary sophistication was associated with mothers' educational attainment and their household income. Together, these findings support mothers' vocabulary sophistication as possible transmission pathway from family background to children's education-related outcomes. Because this pathway is likely causal, at least to some degree, mothers' vocabulary sophistication may be a suitable target for interventions that seek to disrupt the perpetuation of family background inequality in education. That said, we observed very small effect sizes for the role of mothers' speech, suggesting that any to-be-developed interventions that target mothers' speech will achieve modest change to the transmission of family background inequality, even if they are effective. Overall, our research showed that children's differences in education-related outcomes were more strongly associated with their families' socioeconomic resources than with their mothers' speech. This finding emphasises that disrupting family background inequality in education in substantial ways will require addressing socioeconomic conditions that children are raised in.

Glossary of genetic terms

Term	Definition
Genetic Confounding	Genetic confounding occurs when genetic factors influence both an environmental characteristic (e.g., mothers' speech) and an outcome (e.g., a child's education-related outcomes). The association between environment and outcome may be due to shared genetics between parent and child; these shared genetic can create the false impression of a causal environmental effect.
Adoption Study Design	Adopted children share genes with their biological, but not with their adoptive parents. Conversely, adopted children share environments with their adoptive, but not with their environment biological parents. Comparing resemblances of children with their biological relative to their adoptive parents helps discerning genetic (similarities with biological parents) and environmental effects (similarities with adoptive parents).
Twin study design	The classic twin study design relies on comparisons of the phenotypic resemblance between identical (monozygotic) and fraternal (dizygotic) twins to estimate additive genetic, shared, and non-shared environmental influences on a trait. Monozygotic twins share 100% of their genome, while dizygotic twins share on average 50% of their segregating genetic variants; they resemble each other genetically as much as other fraternal siblings. If monozygotic twins are more similar to each other in a given phenotypic trait than dizygotic twins, we can conclude that genetic factors influence people's differences in that trait.
Heritability	Heritability is the proportion of differences in a phenotypic trait (i.e., phenotypic variation) that can be attributed to genetic differences between people in a given population at a given time. Genetic and environmental influences exist in a concerted balance: Individual differences in all traits are heritable, but no trait is 100% heritable.
Phenotype	Phenotype refers to an individual's observable or expressed traits. People's phenotypic differences result from the

	interplay of their genes (genotype) and their environments. In GWAS (below), the behavioural or psychological trait for which DNA variants' associations are tested is referred to as target phenotype.
Genome	The genome is the complete set of genetic information of an organism.
Genotype	A genotype is a scoring of the type of variant present at a given location (i.e., a locus) in the genome, represented for example by the DNA sequence at a specific location, such as CC, CT, TT. Some genotypes contribute to an individual's phenotype or observable traits.
Polygenic scores	Polygenic scores are aggregates of the SNPs (see below) that are spread across the genome and were identified in a GWAS to be associated with a target phenotype. The SNPs that are included in polygenic scores are typically weighted by the effect size of their association in the GWAS; this information is contained in the GWAS summary statistics. Polygenic scores can be computed in any independent (validation) sample, for whom genotypes are available, to index a person's genetic propensity for a target phenotype.
Single-nucleotide polymorphisms (SNPs)	A SNP refers to a base-pair difference in the genome, which occurs at one location of the genome (i.e., single nucleotide), independent of base-pair differences in other locations, and presents in many different (i.e., poly) versions (i.e., morphisms). SNPs are the smallest unit of genetic variation between people. A base-pair is a 'rung in the DNA ladder' that bonds together two bases (i.e., Adenine with Thymine, and Guanine with Cytosine). The human genome includes about three billion base-pairs, and SNPs occur about one in every 300 base-pairs (i.e., there are about ten million SNPs within the human genome).
Genome-wide association studies (GWAS)	GWAS test associations between SNPs across the genome and individual differences in a phenotypic trait, also known as a target phenotype (e.g., years spent in full-time education), in a discovery sample. GWAS produce summary statistics of

	the strength with which each SNP is associated with the target phenotype in the GWAS discovery sample.
Genetic Propensity	An individual's genetic propensity suggests behavioural, cognitive, and affective tendencies or preferences for a particular trait given their inherited DNA differences. These reflect probabilistic rather than deterministic estimates.
Causality and prediction	In statistics, causality is an inference made between two variables, where variable X causes variable Y. Prediction describes the associations between two variables, whereby variable X predicts the occurrence of variable Y, for example when X occurred in time before Y. Observing that variable X predicts variable Y does not imply that X causes Y. In the context of genomic research, polygenic scores are said to predict rather than cause phenotypic differences.

Project publications to date

1. Brown, A., Caspi, A., Fisher, H. L., Moffitt, T. E., Wertz, J., & von Stumm, S. (2026). *The role of mothers' speech for children's education beyond the early years*. *Child Development*. Advance online publication. https://doi.org/10.1093/chidev/aacag097
2. von Stumm, S., Arseneault, L., Caspi, A., Ph.D., Fisher, H. L., Moffitt, T., Sugden, K., … Brown, A. (2026). The role of the ‘word gap’ in educational inequality: A genetically sensitive study. *In Revision. Preprint:* https://doi.org/10.31234/osf.io/6ec5r_v1
3. Wood, E., Brown, A., & von Stumm, S. (2026). Twins and their singleton siblings differ in language, cognition, and social-emotional development. *Child Development*, *97*(3), 649–661. https://doi.org/10.1093/chidev/aacaf029

References

Adair, J. K., Colegrove, K. S.-S., & McManus, M. E. (2017). How the Word Gap Argument Negatively Impacts Young Children of Latinx Immigrants' Conceptualizations of Learning. *Harvard Educational Review*, *87*(3), 309–334. https://doi.org/10.17763/1943-5045-87.3.309

Adamson, L. B., Kaiser, A. P., Tamis-LaMonda, C. S., Owen, M. T., & Dimitrova, N. (2020). The developmental landscape of early parent-focused language intervention. *Early Childhood Research Quarterly*, *50*, 59–67. https://doi.org/10.1016/j.ecresq.2018.11.005

Agnew-Blais, J. C., Wertz, J., Arseneault, L., Belsky, D. W., Danese, A., Pingault, J.-B., Polanczyk, G. V., Sugden, K., Williams, B., & Moffitt, T. E. (2022). Mother's and children's ADHD genetic risk, household chaos and children's ADHD symptoms: A gene–environment correlation study. *Journal of Child Psychology and Psychiatry, 63(10),* 1153–1163. https://doi.org/10.1111/jcpp.13659

Anderson, N. J., Graham, S. A., Prime, H., Jenkins, J. M., & Madigan, S. (2021). Linking Quality and Quantity of Parental Linguistic Input to Child Language Skills: A Meta-Analysis. *Child Development*, *92*(2), 484–501. https://doi.org/10.1111/cdev.13508

Asbury, K., McBride, T., & Rimfeld, K. (2021). *Genetics and early intervention: Exploring ethical and policy questions*. EIF. https://www.eif.org.uk/report/genetics-and-early-intervention-exploring-ethical-and-policy-questions

Babayiğit, S. (2015). The relations between word reading, oral language, and reading comprehension in children who speak English as a first (L1) and second language (L2): A multigroup structural analysis. *Reading and Writing: An Interdisciplinary Journal, 28*(4), 527–544. https://doi.org/10.1007/s11145-014-9536-x

Bakopoulou, I. (2023). Research report—Empowering educational professionals to create strong language provision in early and primary school settings. In *Supporting Spoken Language in the Classroom (SSLiC): London, UK.* [Report]. Supporting Spoken

Language in the Classroom (SSLiC). https://www.ucl.ac.uk/ioe/departments-and-centres/centres/centre-inclusive-education/supporting-spoken-language-classroom-sslic

Balthazar, C. H., & Scott, C. M. (2024). Sentences Are Key: Helping School-Age Children and Adolescents Build Sentence Skills Needed for Real Language. *American Journal of Speech-Language Pathology*, *33*(2), 564–579. https://doi.org/10.1044/2023_AJSLP-23-00038

Barnes, E. M., & Dickinson, D. K. (2017). The Relationship of Head Start Teachers' Academic Language Use and Children's Receptive Vocabulary. *Early Education and Development*, *28*(7), 794–809. https://doi.org/10.1080/10409289.2017.1340069

Baugh, J. (2017). Meaning-Less Differences: Exposing Fallacies and Flaws in "The Word Gap" Hypothesis That Conceal a Dangerous "Language Trap" for Low-Income American Families and Their Children. *International Multilingual Research Journal*. https://www.tandfonline.com/doi/abs/10.1080/19313152.2016.1258189

Beck, I. L., McKeown, M. G., & Kucan, L. (2013). *Bringing Words to Life: Robust Vocabulary Instruction*. Guilford Press.

Bergelson, E., Soderstrom, M., Schwarz, I.-C., Rowland, C. F., Ramírez-Esparza, N., R. Hamrick, L., Marklund, E., Kalashnikova, M., Guez, A., Casillas, M., Benetti, L., Alphen, P. van, & Cristia, A. (2023). Everyday language input and production in 1,001 children from six continents. *Proceedings of the National Academy of Sciences*, *120*(52), e2300671120. https://doi.org/10.1073/pnas.2300671120

Bernstein, B. B. (with Internet Archive). (1971). *Class, codes and control*. London : Routledge and K. Paul. http://archive.org/details/classcodescontro0003bern

Blanden, J., & Gibbons, S. (2006). *The persisitence of poverty across generations: A view from two British cohorts*. The Policy Press. https://eu.alma.exlibrisgroup.com

Blanden, J., Gregg, P., & Macmillan, L. (2007). Accounting for Intergenerational Income Persistence: Noncognitive Skills, Ability and Education. *The Economic Journal*, *117*(519), C43–C60. https://doi.org/10.1111/j.1468-0297.2007.02034.x

Bleses, D., Jensen, P., Slot, P., & Justice, L. (2020). Low-cost teacher-implemented intervention improves toddlers' language and math skills. *Early Childhood Research Quarterly*, *53*, 64–76. https://doi.org/10.1016/j.ecresq.2020.03.001

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, *53*(1), 371–399. https://doi.org/10.1146/annurev.psych.53.100901.135233

Broesch, T. (2021). Motherese. In T. K. Shackelford & V. A. Weekes-Shackelford (Eds.), *Encyclopedia of Evolutionary Psychological Science* (pp. 5263–5264). Springer International Publishing. https://doi.org/10.1007/978-3-319-19650-3_3326

Brown, A., Caspi, A., Fisher, H. L., Moffitt, T., Wertz, J., & von Stumm, S. (2025). Mothers' speech predicts children's differences in cognition, literacy, and educational achievement across the school years. *Preprint:* https://doi.org/10.31235/osf.io/xk7h4

Cabral-Gouveia, C., Menezes, I., & Neves, T. (2023). Educational strategies to reduce the achievement gap: A systematic review. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1155741

Cabrera, N. J., Volling, B. L., & Barr, R. (2018). Fathers Are Parents, Too! Widening the Lens on Parenting for Children's Development. *Child Development Perspectives*, *12*(3), 152–157. https://doi.org/10.1111/cdep.12275

Carneiro, P., Cattan, S., Dearden, L., Krutikova, S., Macmillan, L., & van der Erve, L. (2020). *The long shadow of deprivation: Differences in opportunities across England*. https://ifs.org.uk/publications/long-shadow-deprivation-differences-opportunities-across-england

Caro, D. H., McDonald, J. T., & Willms, J. D. (2009). Socio-economic status and academic achievement trajectories from childhood to adolescence. *Canadian Journal of Education/Revue Canadienne de l'éducation*, *32*(3), 558–590.

Caspi, A., Moffitt, T. E., Morgan, J., Rutter, M., Taylor, A., Arseneault, L., Tully, L., Jacobs, C., Kim-Cohen, J., & Polo-Tomas, M. (2004). Maternal expressed emotion predicts children's antisocial behavior problems: Using monozygotic-twin differences to identify environmental effects on behavioral development. *Developmental Psychology*, *40*(2), 149–161. https://doi.org/10.1037/0012-1649.40.2.149

Chen, J., Justice, L. M., Tambyraja, S. R., & Sawyer, B. (2020). Exploring the mechanism through which peer effects operate in preschool classrooms to influence language growth. *Early Childhood Research Quarterly*, *53*, 1–10. https://doi.org/10.1016/j.ecresq.2020.02.002

Choi, S. W., Mak, T. S.-H., & O'Reilly, P. F. (2020). Tutorial: A guide to performing polygenic risk score analyses. *Nature Protocols*, *15*(9), 2759–2772. https://doi.org/10.1038/s41596-020-0353-1

Clegg, J., & Ginsborg, J. (2006). *Language and Social Disadvantage: Theory into Practice*. John Wiley & Sons.

Corak, M. (2006). *Do Poor Children Become Poor Adults? Lessons from a Cross Country Comparison of Generational Earnings Mobility*. https://doi.org/10.2139/ssrn.889034

Curtin, M. (2020). Dialect: Social class. *The International Encyclopedia of Linguistic Anthropology*, 1–9.

Cushing, I. (2021). 'Say it like the Queen': The standard language ideology and language policy making in English primary schools. *Language, Culture and Curriculum*, *34*(3), 321–336. https://doi.org/10.1080/07908318.2020.1840578

Cychosz, M., Edwards, J. R., Bernstein Ratner, N., Torrington Eaton, C., & Newman, R. S. (2021). Acoustic-Lexical Characteristics of Child-Directed Speech Between 7 and 24 Months and Their Impact on Toddlers' Phonological Processing. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.712647

d'Apice, K., Latham, R. M., & von Stumm, S. (2019). A naturalistic home observational approach to children's language, cognition, and behavior. *Developmental Psychology*, *55*, 1414–1427. https://doi.org/10.1037/dev0000733

Dailey, S., & Bergelson, E. (2022). Language input to infants of different socioeconomic statuses: A quantitative meta-analysis. *Developmental Science*, *25*(3), e13192. https://doi.org/10.1111/desc.13192

De Zeeuw, E. L., De Geus, E. J. C., & Boomsma, D. I. (2015). Meta-analysis of twin studies highlights the importance of genetic variation in primary school educational achievement. *Trends in Neuroscience and Education*, *4*(3), 69–76. https://doi.org/10.1016/j.tine.2015.06.001

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence*, *35*(1), 13–21. https://doi.org/10.1016/j.intell.2006.02.001

Department for Work & Pensions. (2024). *Workless households and educational attainment statutory indicators 2024*. GOV.UK. https://www.gov.uk/government/publications/workless-households-and-educational-attainment-statutory-indicators-2024/workless-households-and-educational-attainment-statutory-indicators-2024

Dickinson, D. K., Golinkoff, R. M., & Hirsh-Pasek, K. (2010). Speaking Out for Language: Why Language Is Central to Reading Development. *Educational Researcher*, *39*(4), 305–310. https://doi.org/10.3102/0013189X10370204

Dickinson, D. K., & Porche, M. V. (2011). Relation Between Language Experiences in Preschool Classrooms and Children's Kindergarten and Fourth-Grade Language and Reading Abilities. *Child Development*, *82*(3), 870–886. https://doi.org/10.1111/j.1467-8624.2011.01576.x

Dolean, D., Melby-Lervåg, M., Tincas, I., Damsa, C., & Lervåg, A. (2019). Achievement gap: Socioeconomic status affects reading development beyond language and cognition in children facing poverty. *Learning and Instruction*, *63*, 101218. https://doi.org/10.1016/j.learninstruc.2019.101218

Doust, C., Fontanillas, P., Eising, E., Gordon, S. D., Wang, Z., Alagöz, G., Molz, B., Pourcain, B. S., Francks, C., Marioni, R. E., Zhao, J., Paracchini, S., Talcott, J. B., Monaco, A. P., Stein, J. F., Gruen, J. R., Olson, R. K., Willcutt, E. G., DeFries, J. C., … Luciano, M. (2022). Discovery of 42 genome-wide significant loci associated with dyslexia. *Nature Genetics*, *54*(11), 1621–1629. https://doi.org/10.1038/s41588-022-01192-y

Dudley-Marling, C., & Lucas, K. (2009). Pathologizing the Language and Culture of Poor Children. *Language Arts*, *86*(5), 362–370.

Duff, F. J., Reen, G., Plunkett, K., & Nation, K. (2015). Do infant vocabulary skills predict school-age language and literacy outcomes? *Journal of Child Psychology and Psychiatry*, *56*(8), 848–856. https://doi.org/10.1111/jcpp.12378

Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *WIREs Cognitive Science*, *3*(3), 377–386. https://doi.org/10.1002/wcs.1176

Durham, R., Hammer, C., Tomblin, J., & Catts, H. (2007). Kindergarten oral language skill: A key variable in the intergenerational transmission of socioeconomic status. *Research in Social Stratification and Mobility*, *25*, 294–305. https://doi.org/10.1016/j.rssm.2007.03.001

Early, E., Miller, S., Dunne, L., Thurston, A., & Filiz, M. (2020). The influence of socio-economic background and gender on school attainment in the United Kingdom: A systematic review. *Review of Education*, *8*(1), 120–152. https://doi.org/10.1002/rev3.3175

Eising, E., Mirza-Schreiber, N., de Zeeuw, E. L., Wang, C. A., Truong, D. T., Allegrini, A. G., Shapland, C. Y., Zhu, G., Wigg, K. G., Gerritse, M. L., Molz, B., Alagöz, G., Gialluisi, A., Abbondanza, F., Rimfeld, K., van Donkelaar, M., Liao, Z., Jansen, P. R., Andlauer, T. F. M., … Fisher, S. E. (2022). Genome-wide analyses of individual differences in quantitatively assessed reading- and language-related skills in up to 34,000 people. *Proceedings of the National Academy of Sciences*, *119*(35), e2202764119. https://doi.org/10.1073/pnas.2202764119

Ellwood-Lowe, M. E., Foushee, R., & Srinivasan, M. (2022). What causes the word gap? Financial concerns may systematically suppress child-directed speech. *Developmental Science*, *25*(1), e13151. https://doi.org/10.1111/desc.13151

Ermisch, J., & Francesconi, M. (2001). Family Matters: Impacts of Family Background on Educational Attainments. *Economica*, *68*(270), 137–156. https://doi.org/10.1111/1468-0335.00239

Eurostat. (2024). *Gini coefficient of equivalised disposable income*. Eurostat. https://ec.europa.eu/eurostat/databrowser/view/tessi190/default/table?lang=en

Ezeizabarrena, M.-J., & Garcia Fernandez, I. (2018). Length of Utterance, in Morphemes or in Words?: MLU3-w, a Reliable Measure of Language Development in Early Basque. *Frontiers in Psychology*, *8*. https://www.frontiersin.org/articles/10.3389/fpsyg.2017.02265

Fernald, A., Taeschner, T., Dunn, J., Papousek, M., Boysson-Bardies, B. de, & Fukui, I. (1989). A cross-language study of prosodic modifications in mothers' and fathers' speech to preverbal infants. *Journal of Child Language*, *16*(3), 477–501. https://doi.org/10.1017/S0305000900010679

Fernald, A., & Weisleder, A. (2015). Twenty Years after "Meaningful Differences," It's Time to Reframe the "Deficit" Debate about the Importance of Children's Early Language Experience. *Human Development*, *58*(1), 1–4. https://doi.org/10.1159/000375515

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2021). *Variability and Consistency in Early Language Learning: The Wordbank Project*. MIT Press.

Fry, R. (2023, August 3). Almost 1 in 5 stay-at-home parents in the U.S. are dads. *Pew Research Center*. https://www.pewresearch.org/short-reads/2023/08/03/almost-1-in-5-stay-at-home-parents-in-the-us-are-dads/

Furrow, D., Nelson, K., & Benedict, H. (1979). Mothers' speech to children and syntactic development: Some simple relationships. *Journal of Child Language*, *6*(3), 423–442. https://doi.org/10.1017/s0305000900002464

Gibbs, R., Belmont, J., Hardenbol, P., Willis, T. D., Yu, F., Yang, H., Ch'ang, L. Y., & et al. (2003). The International HapMap Project. *Nature*. https://doi.org/10.1038/nature02168

Glas, L., Rossi, C., Hamdi Sultan, R., Batailler, C., & Bellemmouche, H. (2018). Activity types and child-directed speech: A comparison between French, Tunisian Arabic and English. *Canadian Journal of Linguistics/Revue Canadienne de Linguistique*, *63*, 1–34. https://doi.org/10.1017/cnj.2018.20

Golden, C. J., & Bennett, R. (2024). Clinical Integration of Neuropsychological Test Results. CRC Press.

Golinkoff, R. M., Hoff, E., Rowe, M. L., Tamis-LeMonda, C. S., & Hirsh-Pasek, K. (2019). Language Matters: Denying the Existence of the 30-Million-Word Gap Has Serious Consequences. *Child Development*, *90*(3), 985–992. https://doi.org/10.1111/cdev.13128

Gottfried, M. A. (2010). Evaluating the Relationship Between Student Attendance and Achievement in Urban Elementary and Middle Schools: An Instrumental Variables Approach. *American Educational Research Journal*, *47*(2), 434–465. https://doi.org/10.3102/0002831209350494

GOV.UK. (2023). *Academic year 2022/23—Key stage 2 attainment*. GOV.UK. https://explore-education-statistics.service.gov.uk/find-statistics/key-stage-2-attainment

Greenwood, C. R., Schnitz, A. G., Carta, J. J., Wallisch, A., & Irvin, D. W. (2020). A systematic review of language intervention research with low-income families: A word gap prevention perspective. *Early Childhood Research Quarterly*, *50*, 230–245. https://doi.org/10.1016/j.ecresq.2019.04.001

Gustavson, K., von Soest, T., Karevold, E., & Røysamb, E. (2012). Attrition and generalizability in longitudinal studies: Findings from a 15-year population-based study and a Monte Carlo simulation study. *BMC Public Health*, *12*(1), 918. https://doi.org/10.1186/1471-2458-12-918

Harden, K. P. (2021). *The Genetic Lottery: Why DNA Matters for Social Equality*. Princeton University Press. https://press.princeton.edu/books/hardcover/9780691190808/the-genetic-lottery

Haring Biel, C., Buzhardt, J., Brown, J. A., Romano, M. K., Lorio, C. M., Windsor, K. S., Kaczmarek, L. A., Gwin, R., Sandall, S. S., & Goldstein, H. (2020). Language interventions taught to caregivers in homes and classrooms: A review of intervention and implementation fidelity. *Early Childhood Research Quarterly*, *50*, 140–156. https://doi.org/10.1016/j.ecresq.2018.12.002

Harries, V., & Brown, A. (2019). The association between use of infant parenting books that promote strict routines, and maternal depression, self-efficacy, and parenting confidence. *Early Child Development and Care*, *189*(8), 1339–1350. https://doi.org/10.1080/03004430.2017.1378650

Hart, B., & Risley, T. R. (1995). *Meaningful Differences in the Everyday Experience of Young American Children*. P.H. Brookes.

Hart, B., & Risley, T. R. (2003). The Early Catastrophe. *American Educator*. https://www.aft.org/ae/spring2003/hart_risley

Hart, S. A., Soden, B., Johnson, W., Schatschneider, C., & Taylor, J. (2013). Expanding the environment: Gene × school-level SES interaction on reading comprehension. *Journal of Child Psychology and Psychiatry*, *54*(10), 1047–1055. https://doi.org/10.1111/jcpp.12083

Hartas, D. (2011). Families' social backgrounds matter: Socio-economic factors, home learning and young children's language, literacy and social outcomes. *British Educational Research Journal*, *37*(6), 893–914. https://doi.org/10.1080/01411926.2010.506945

Haworth, C. M. a, Wright, M. J., Luciano, M., Martin, N. G., de Geus, E. J. C., van Beijsterveldt, C. E. M., Bartels, M., Posthuma, D., Boomsma, D. I., Davis, O. S. P., Kovas, Y., Corley, R. P., Defries, J. C., Hewitt, J. K., Olson, R. K., Rhea, S., Wadsworth, S. J., Iacono, W. G., McGue, M., … Plomin, R. (2010). The heritability of general cognitive ability increases linearly from childhood to young adulthood. *Molecular Psychiatry*, *15*(11), 1112–1120. https://doi.org/10.1038/mp.2009.55

Hayes, A. F. (2009). Beyond Baron and Kenny: Statistical mediation analysis in the new millennium. *Communication Monographs*, *76*(4), 408–420. https://doi.org/10.1080/03637750903310360

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *The Behavioral and Brain Sciences*, *33*(2–3), 61–83; discussion 83-135. https://doi.org/10.1017/S0140525X0999152X

Hirsh-Pasek, K., Adamson, L. B., Bakeman, R., Owen, M. T., Golinkoff, R. M., Pace, A., Yust, P. K. S., & Suma, K. (2015). The Contribution of Early Communication Quality to Low-Income Children's Language Success. *Psychological Science*, *26*(7), 1071–1083. https://doi.org/10.1177/0956797615581493

Hodge, L., Little, A., & Weldon, M. (2021). *GCSE attainment and lifetime earnings*. Department for Education. https://www.voced.edu.au/content/ngv%3A90968

Hoff, E. (2003). The Specificity of Environmental Influence: Socioeconomic Status Affects Early Vocabulary Development Via Maternal Speech. *Child Development*, *74*(5), 1368–1378. https://doi.org/10.1111/1467-8624.00612

Hoff, E. (2013). Interpreting the Early Language Trajectories of Children from Low SES and Language Minority Homes: Implications for Closing Achievement Gaps. *Developmental Psychology*, *49*(1), 4–14. https://doi.org/10.1037/a0027238

Hoff, E., & Naigles, L. (2002). How Children Use Input to Acquire a Lexicon. *Child Development*, *73*(2), 418–433. https://doi.org/10.1111/1467-8624.00415

Hoff-Ginsberg, E. (1991). Mother-child conversation in different social classes and communicative settings. *Child Development*, *62*(4), 782–796. https://doi.org/10.2307/1131177

Hoff-Ginsberg, E. (1998). The relation of birth order and socioeconomic status to children's language experience and language development. *Applied Psycholinguistics*, *19*(4), 603–629. https://doi.org/10.1017/S0142716400010389

Hudson, E. (2022). *Exploring the Experience of Parenting when using Social Media: A Grounded Theory Study*. https://doi.org/10.18745/th.25473

Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cognitive Psychology*, *45*(3), 337–374. https://doi.org/10.1016/S0010-0285(02)00500-5

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*(4), 343–365. https://doi.org/10.1016/j.cogpsych.2010.08.002

IFS. (2024). *The latest picture on school funding and costs in England*. Institute for Fiscal Studies. https://ifs.org.uk/articles/latest-picture-school-funding-and-costs-england

International Human Genome Sequencing Consortium. (2001). Initial sequencing and analysis of the human genome. *Nature*, *409*(6822), 860–921. https://doi.org/10.1038/35057062

Jeynes, W. H. (2016). Meta-Analysis on the Roles of Fathers in Parenting: Are They Unique? *Marriage & Family Review*, *52*(7). https://doi.org/10.1080/01494929.2016.1157121

Jones, G., Cabiddu, F., Barrett, D. J. K., Castro, A., & Lee, B. (2023). How the characteristics of words in child-directed speech differ from adult-directed speech to influence children's productive vocabularies. *First Language*, *43*(3), 253–282. https://doi.org/10.1177/01427237221150070

Joyce, R., & Xu, X. (2019). *Inequalities in the twenty-first century: Introducing the IFS Deaton Review*. The IFS. https://doi.org/10.1920/BN.IFS.2019.IDRBN1

Justice, L. M., Petscher, Y., Schatschneider, C., & Mashburn, A. (2011). Peer Effects in Preschool Classrooms: Is Children's Language Growth Associated With Their Classmates' Skills? *Child Development*, *82*(6), 1768–1777. https://doi.org/10.1111/j.1467-8624.2011.01665.x

Kelly, Y., Sacker, A., Del Bono, E., Francesconi, M., & Marmot, M. (2011). What role for the home learning environment and parenting in reducing the socioeconomic gradient in child development? Findings from the Millennium Cohort Study. *Archives of Disease in Childhood*, *96*(9), 832–837. https://doi.org/10.1136/adc.2010.195917

Kempe, V., Ota, M., & Schaeffler, S. (2024). Does child-directed speech facilitate language development in all domains? A study space analysis of the existing evidence. *Developmental Review*, *72*, 101121. https://doi.org/10.1016/j.dr.2024.101121

Kidd, E., Donnelly, S., & Christiansen, M. H. (2018). Individual Differences in Language Acquisition and Processing. *Trends in Cognitive Sciences*, *22*(2), 154–169. https://doi.org/10.1016/j.tics.2017.11.006

Killingly, C., Graham, L. J., Tancredi, H., & [include any additional authors if “et al.” covers more — list up to 20 total authors]. (2025). Reciprocal relationships among reading and vocabulary over time: A longitudinal study from grade 1 to 5. *Reading and Writing, 38*, 605–625. https://doi.org/10.1007/s11145-024-10522-x

Kircher, R., & Fox, S. (2021). Multicultural London English and its speakers: A corpus-informed discourse study of standard language ideology and social stereotypes. *Journal of Multilingual and Multicultural Development*, *42*(9), 792–810. https://doi.org/10.1080/01434632.2019.1666856

Kraus, M. W., Torrez, B., Park, J. W., & Ghayebi, F. (2019). Evidence for the reproduction of social class in brief speech. *Proceedings of the National Academy of Sciences*, *116*(46), 22998–23003. https://doi.org/10.1073/pnas.1900500116

Lee, J. J., Wedow, R., Okbay, A., Kong, E., Maghzian, O., Zacher, M., Nguyen-Viet, T. A., Bowers, P., Sidorenko, J., Karlsson Linnér, R., Fontana, M. A., Kundu, T., Lee, C., Li, H., Li, R., Royer, R., Timshel, P. N., Walters, R. K., Willoughby, E. A., … Cesarini, D. (2018). Gene discovery and polygenic prediction from a genome-wide association study of educational attainment in 1.1 million individuals. *Nature Genetics*, *50*(8), 1112–1121. https://doi.org/10.1038/s41588-018-0147-3

Lehrl, S., Evangelou, M., & Sammons, P. (2020). The home learning environment and its role in shaping children’s educational development. *School Effectiveness and School Improvement*, *31*(1), 1–6. https://doi.org/10.1080/09243453.2020.1693487

Li, S. D. (2011). *Testing Mediation Using Multiple Regression and Structural Equation Modeling Analyses in Secondary Data*. *35*(3). https://doi.org/10.1177/0193841X11412069

Lippi-Green, R. (2011). *English with an Accent: Language, Ideology and Discrimination in the United States* (2nd ed.). Routledge. https://doi.org/10.4324/9780203348802

Liu, H.-M., Tsao, F.-M., & Kuhl, P. K. (2009). Age-related changes in acoustic modifications of Mandarin maternal speech to preverbal infants and five-year-old children: A longitudinal study. *Journal of Child Language*, *36*(4), 909–922. https://doi.org/10.1017/S030500090800929X

Liu, J., Peng, P., Zhao, B., & Luo, L. (2022). Socioeconomic Status and Academic Achievement in Primary and Secondary Education: A Meta-analytic Review. *Educational Psychology Review*, *34*(4), 2867–2896. https://doi.org/10.1007/s10648-022-09689-y

Lockhart, C., Bright, J., Ahmadzadeh, Y., Breen, G., Bristow, S., Boyd, A., Downs, J., Hotopf, M., Palaiologou, E., Rimfeld, K., Maxwell, J., Malanchini, M., McAdams, T. A., McMillan, A., Plomin, R., & Eley, T. C. (2023). Twins Early Development Study (TEDS): A genetically sensitive investigation of mental health outcomes in the mid-twenties. *JCPP Advances, 3*(2), Article e12154. https://doi.org/10.1002/jcv2.12154

MacKinnon, D. P., Fairchild, A. J., & Fritz, M. S. (2007). Mediation Analysis. *Annual Review of Psychology*, *58*, 593. https://doi.org/10.1146/annurev.psych.58.110405.085542

MacWhinney, B. (2000). The CHILDES Project. *Computational Linguistics*, *26*(4), 657–657.

Magalhães, S., Carneiro, L., Limpo, T., & Filipe, M. (2020). Executive functions predict literacy and mathematics achievements: The unique contribution of cognitive flexibility in grades 2, 4, and 6. *Child Neuropsychology*, *26*(7), 934–952. https://doi.org/10.1080/09297049.2020.1740188

Magaña, A. B., Goldstein, M. J., Karno, M., Miklowitz, D. J., Jenkins, J., & Falloon, I. R. H. (1986). A brief method for assessing expressed emotion in relatives of psychiatric patients. *Psychiatry Research*, *17*(3), 203–212. https://doi.org/10.1016/0165-1781(86)90049-1

Mahurin, -Smith Jamie, Mills, M. T., & Chang, R. (2021). Rare Vocabulary Production in School-Age Narrators From Low-Income Communities. *Language, Speech, and Hearing Services in Schools*, *52*(1), 51–63. https://doi.org/10.1044/2020_LSHSS-19-00120

Manolio, T. A., Collins, F. S., Cox, N. J., Goldstein, D. B., Hindorff, L. A., Hunter, D. J., McCarthy, M. I., Ramos, E. M., Cardon, L. R., Chakravarti, A., Cho, J. H., Guttmacher, A. E., Kong, A., Kruglyak, L., Mardis, E., Rotimi, C. N., Slatkin, M., Valle, D., Whittemore, A. S., … Visscher, P. M. (2009). Finding the missing heritability of complex diseases. *Nature*, *461*(7265), 747–753. https://doi.org/10.1038/nature08494

Marulis, L. M., & Neuman, S. B. (2010). The Effects of Vocabulary Intervention on Young Children's Word Learning: A Meta-Analysis. *Review of Educational Research*, *80*(3), 300–335. https://doi.org/10.3102/0034654310377087

Matychuk, P. (2005). The role of child-directed speech in language acquisition: A case study. *Language Sciences*, *27*(3), 301–379. https://doi.org/10.1016/j.langsci.2004.04.004

McCarthy, P. M., & Jarvis, S. (2010). MTLD, vocd-D, and HD-D: A validation study of sophisticated approaches to lexical diversity assessment. *Behavior Research Methods*, *42*(2), 381–392. https://doi.org/10.3758/BRM.42.2.381

McWayne, C., Downer, J. T., Campos, R., & Harris, R. D. (2013). Father Involvement During Early Childhood and Its Association with Children's Early Learning: A Meta-Analysis. *Early Education and Development*, *24*(6). https://doi.org/10.1080/10409289.2013.746932

Ministry of Housing, Communities & Local Government. (2021). *Supporting Families—2021-22 and beyond*. GOV.UK. https://www.gov.uk/government/publications/supporting-families-2021-to-2022-and-beyond/supporting-families-2021-22-and-beyond

Mirheidari, B., Bittar, A., Cummins, N., Downs, J., Fisher, H. L., & Christensen, H. (2024). Automatic detection of expressed emotion from Five-Minute Speech Samples:

Challenges and opportunities. *PLOS ONE*, *19*(3), e0300518. https://doi.org/10.1371/journal.pone.0300518

Moffitt, T. E. & E-Risk Study Team. (2002). Teen-aged mothers in contemporary Britain. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *43*(6), 727–742. https://doi.org/10.1111/1469-7610.00082

Montag, J. L. (2019). Differences in sentence complexity in the text of children's picture books and child-directed speech. *First Language*, *39*(5), 527–546. https://doi.org/10.1177/0142723719849996

Moore, G. F., & Littlecott, H. J. (2015). School- and Family-Level Socioeconomic Status and Health Behaviors: Multilevel Analysis of a National Survey in Wales, United Kingdom. *Journal of School Health*, *85*(4), 267–275. https://doi.org/10.1111/josh.12242

Morosoli, J. J., Colodro-Conde, L., Barlow, F. K., & Medland, S. E. (2024). Scientific clickbait: Examining media coverage and readability in genome-wide association research. *PLOS ONE*, *19*(1), e0296323. https://doi.org/10.1371/journal.pone.0296323

Mueller, K. D., Koscik, R. L., Clark, L. R., Hermann, B. P., Johnson, S. C., & Turkstra, L. S. (2018). The Latent Structure and Test–Retest Stability of Connected Language Measures in the Wisconsin Registry for Alzheimer's Prevention (WRAP). *Archives of Clinical Neuropsychology*, *33*(8), 993–1005. https://doi.org/10.1093/arclin/acx116

Mueller, K. D., Koscik, R. L., Hermann, B. P., Johnson, S. C., & Turkstra, L. S. (2018). Declines in Connected Language Are Associated with Very Early Mild Cognitive Impairment: Results from the Wisconsin Registry for Alzheimer's Prevention. *Frontiers in Aging Neuroscience*, *9*. https://www.frontiersin.org/articles/10.3389/fnagi.2017.00437

Nag, S., Vagh, S. B., Dulay, K. M., Snowling, M., Donolato, E., & Melby-Lervåg, M. (2024). Home learning environments and children's language and literacy skills: A meta-analytic review of studies conducted in low- and middle-income countries. *Psychological Bulletin*, *150*(2), 132–153. https://doi.org/10.1037/bul0000417

Nagy, W., & Townsend, D. (2012). Words as Tools: Learning Academic Vocabulary as Language Acquisition. *Reading Research Quarterly*, *47*(1), 91–108. https://doi.org/10.1002/RRQ.011

NCD Risk Factor Collaboration (NCD-RisC). (2016). A century of trends in adult human height. *eLife*, *5*, e13410. https://doi.org/10.7554/eLife.13410

Nielsen, M., Haun, D., Kärtner, J., & Legare, C. H. (2017). The persistent sampling bias in developmental psychology: A call to action. *Journal of Experimental Child Psychology*, *162*, 31–38. https://doi.org/10.1016/j.jecp.2017.04.017

Nivard, M. G., Belsky, D. W., Harden, K. P., Baier, T., Andreassen, O. A., Ystrøm, E., Bergen, E. van, & Lyngstad, T. H. (2022). Neither nature nor nurture: Using extended pedigree data to elucidate the origins of indirect genetic effects on offspring educational outcomes. In *PsyArXiv*. https://doi.org/10.31234/osf.io/bhpm5

Ochs, E., & Schieffelin, B. (2017). Language Socialization: An Historical Overview. In P. A. Duff & S. May (Eds.), *Language Socialization* (pp. 1–14). Springer International Publishing. https://doi.org/10.1007/978-3-319-02327-4_1-2

Odgers, C. L., Caspi, A., Bates, C. J., Sampson, R. J., & Moffitt, T. E. (2012). Systematic social observation of children’s neighborhoods using Google Street View: A reliable and cost-effective method. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *53*(10), 1009–1017. https://doi.org/10.1111/j.1469-7610.2012.02565.x

Odgers, C. L., Caspi, A., Russell, M. A., Sampson, R. J., Arseneault, L., & Moffitt, T. E. (2012). Supportive parenting mediates neighborhood socioeconomic disparities in children’s antisocial behavior from ages 5 to 12. *Development and Psychopathology*, *24*(3), 705–721. https://doi.org/10.1017/S0954579412000326

Office for National Statistics. (2023, January 25). *Household income inequality, UK: financial year ending 2022*. Office for National Statistics. https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/bulletins/householdincomeinequalityfinancial/financialyearending2022

Okbay, A., Wu, Y., Wang, N., Jayashankar, H., Bennett, M., Nehzati, S. M., Sidorenko, J., Kweon, H., Goldman, G., Gjorgjieva, T., Jiang, Y., Hicks, B., Tian, C., Hinds, D. A., Ahlskog, R., Magnusson, P. K. E., Oskarsson, S., Hayward, C., Campbell, A., … Young, A. I. (2022). Polygenic prediction of educational attainment within and between families from genome-wide association analyses in 3 million individuals. *Nature Genetics*, *54*(4), 437–449. https://doi.org/10.1038/s41588-022-01016-z

Oslund, E. L., Clemens, N. H., Simmons, D. C., Smith, S. L., & Simmons, L. E. (2016). How vocabulary knowledge of middle-school students from low socioeconomic backgrounds influences comprehension processes and outcomes. *Learning and Individual Differences*, *45*, 159–165. https://doi.org/10.1016/j.lindif.2015.11.013

Oxley, F. A. R., Wilding, K., & von Stumm, S. (2024). DNA and IQ: Big deal or much ado about nothing? – A meta-analysis. *Intelligence*, *107*, 101871. https://doi.org/10.1016/j.intell.2024.101871

Pace, A., Alper, R., Burchinal, M. R., Golinkoff, R. M., & Hirsh-Pasek, K. (2019). Measuring success: Within and cross-domain predictors of academic and social trajectories in elementary school. *Early Childhood Research Quarterly*, *46*, 112–125. https://doi.org/10.1016/j.ecresq.2018.04.001

Pace, A., Luo, R., Hirsh-Pasek, K., & Golinkoff, R. M. (2017). Identifying Pathways Between Socioeconomic Status and Language Development. *Annual Review of Linguistics*, *3*(Volume 3, 2017), 285–308. https://doi.org/10.1146/annurev-linguistics-011516-034226

Pancsofar, N. (2020). Fathers' Language Input and Early Child Language Development. In H. E. Fitzgerald, K. von Klitzing, N. J. Cabrera, J. Scarano de Mendonça, & T. Skjøthaug (Eds.), *Handbook of Fathers and Child Development: Prenatal to Preschool* (pp. 393–409). Springer International Publishing. https://doi.org/10.1007/978-3-030-51027-5_23

Pancsofar, N., & Vernon-Feagans, L. (2006). Mother and father language input to young children: Contributions to later language development. *Journal of Applied*

Developmental Psychology, *27*(6), 571–587. https://doi.org/10.1016/j.appdev.2006.08.003

Pasaniuc, B., & Price, A. L. (2017). Dissecting the genetics of complex traits using summary association statistics. *Nature Reviews Genetics*, *18*(2), 117–127. https://doi.org/10.1038/nrg.2016.142

Patel, D., Krems, J. A., Stout, M. E., Byrd-Craven, J., & Hawkins, M. A. W. (2023). Parents of Children With High Weight Are Viewed as Responsible for Child Weight and Thus Stigmatized. *Psychological Science*, *34*(1), 35–46. https://doi.org/10.1177/09567976221124951

Pechey, R., & Monsivais, P. (2016). Socioeconomic inequalities in the healthiness of food choices: Exploring the contributions of food expenditures. *Preventive Medicine*, *88*, 203–209. https://doi.org/10.1016/j.ypmed.2016.04.012

Pensiero, N., & Schoon, I. (2019). *Social inequalities in educational attainment: The changing impact of parents' social class, social status, education and family income, England 1986 and 2010*. https://doi.org/10.1332/175795919X15468755933380

Perszyk, D. R., & Waxman, S. R. (2018). Linking Language and Cognition in Infancy. *Annual Review of Psychology*, *69*(1), 231–250. https://doi.org/10.1146/annurev-psych-122216-011701

Pickett, K. E., & Wilkinson, R. G. (2015). Income inequality and health: A causal review. *Social Science & Medicine*, *128*, 316–326. https://doi.org/10.1016/j.socscimed.2014.12.031

Plenty, S., & Mood, C. (2016). Money, Peers and Parents: Social and Economic Aspects of Inequality in Youth Wellbeing. *Journal of Youth and Adolescence*, *45*(7), 1294–1308. https://doi.org/10.1007/s10964-016-0430-5

Plomin, R., & von Stumm, S. (2018). The new genetics of intelligence. *Nature Reviews Genetics*, *19*(3), 148–159. https://doi.org/10.1038/nrg.2017.104

Plomin, R., & von Stumm, S. (2022). Polygenic scores: Prediction versus explanation. *Molecular Psychiatry*, *27*(1), 49–52. https://doi.org/10.1038/s41380-021-01348-y

Polderman, T. J. C., Benyamin, B., de Leeuw, C. A., Sullivan, P. F., van Bochoven, A., Visscher, P. M., & Posthuma, D. (2015). Meta-analysis of the heritability of human traits based on fifty years of twin studies. *Nature Genetics*, *47*(7), 702–709. https://doi.org/10.1038/ng.3285

Ratcliff, N. J., Costner, R. H., Carroll, K. L., Jones, C. R., Sheehan, H. C., & Hunt, G. H. (2016). Causes of and Solutions to the Achievement Gap: Teachers' Perceptions. *Teacher Educators' Journal*, *9*, 97–111.

Reggin, L. D., Muraki, E. J., & Pexman, P. M. (2021). Development of Abstract Word Knowledge. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.686478

Reiss, F. (2013). Socioeconomic inequalities and mental health problems in children and adolescents: A systematic review. *Social Science & Medicine*, *90*, 24–31.

Rietveld, C. A., Medland, S. E., Derringer, J., Yang, J., Esko, T., Martin, N. W., Westra, H.-J., Shakhbazov, K., Abdellaoui, A., Agrawal, A., Albrecht, E., Alizadeh, B. Z., Amin, N., Barnard, J., Baumeister, S. E., Benke, K. S., Bielak, L. F., Boatman, J. A., Boyle, P. A., … Koellinger, P. D. (2013). GWAS of 126,559 Individuals Identifies Genetic Variants Associated with Educational Attainment. *Science*, *340*(6139), 1467–1471. https://doi.org/10.1126/science.1235488

Roberts, C. (2010). Language Socialization in the Workplace. *Annual Review of Applied Linguistics*, *30*, 211–227. https://doi.org/10.1017/S0267190510000127

Roby, E., & Scott, R. M. (2022). Financial concern reduces child directed speech in a socioeconomically diverse sample. *Scientific Reports*, *12*(1), 9173. https://doi.org/10.1038/s41598-022-13177-2

Rowe, M. L. (2008). Child-directed speech: Relation to socioeconomic status, knowledge of child development and child vocabulary skill*. *Journal of Child Language*, *35*(1), 185–205. https://doi.org/10.1017/S0305000907008343

Rowe, M. L. (2012). A Longitudinal Investigation of the Role of Quantity and Quality of Child-Directed Speech in Vocabulary Development. *Child Development*, *83*(5), 1762–1774. https://doi.org/10.1111/j.1467-8624.2012.01805.x

Rowe, M. L. (2018). Understanding Socioeconomic Differences in Parents' Speech to Children. *Child Development Perspectives*, *12*(2), 122–127. https://doi.org/10.1111/cdep.12271

Rowe, M. L., Coker, D., & Pan, B. A. (2004). A Comparison of Fathers' and Mothers' Talk to Toddlers in Low-income Families. *Social Development*, *13*(2), 278–291. https://doi.org/10.1111/j.1467-9507.2004.000267.x

Rowe, M. L., Leech, K. A., & Cabrera, N. (2017). Going Beyond Input Quantity: Wh-Questions Matter for Toddlers' Language and Cognitive Development. *Cognitive Science*, *41*(S1), 162–179. https://doi.org/10.1111/cogs.12349

Rowe, M. L., & Snow, C. E. (2020). Analyzing input quality along three dimensions: Interactive, linguistic, and conceptual. *Journal of Child Language*, *47*(1), 5–21. https://doi.org/10.1017/S0305000919000655

Savage, J. E., Jansen, P. R., Stringer, S., Watanabe, K., Bryois, J., de Leeuw, C. A., Nagel, M., Awasthi, S., Barr, P. B., Coleman, J. R. I., Grasby, K. L., Hammerschlag, A. R., Kaminski, J. A., Karlsson, R., Krapohl, E., Lam, M., Nygaard, M., Reynolds, C. A., Trampush, J. W., … Posthuma, D. (2018). Genome-wide association meta-analysis in 269,867 individuals identifies new genetic and functional links to intelligence. *Nature Genetics*, *50*(7), 912–919. https://doi.org/10.1038/s41588-018-0152-6

Schleppegrell, M. J. (2001). Linguistic Features of the Language of Schooling. *Linguistics and Education*, *12*(4), 431–459. https://doi.org/10.1016/S0898-5898(01)00073-0

Schwab, J. F., & Lew-Williams, C. (2016). Language learning, socioeconomic status, and child-directed speech. *WIREs Cognitive Science*, *7*(4), 264–275. https://doi.org/10.1002/wcs.1393

Schwab, J. F., Rowe, M. L., Cabrera, N., & Lew-Williams, C. (2018). Fathers' repetition of words is coupled with children's vocabularies. *Journal of Experimental Child Psychology*, *166*, 437–450. https://doi.org/10.1016/j.jecp.2017.09.012

Selzam, S., Ritchie, S. J., Pingault, J.-B., Reynolds, C. A., O'Reilly, P. F., & Plomin, R. (2019). Comparing Within- and Between-Family Polygenic Score Prediction. *The*

American Journal of Human Genetics, *105*(2), 351–363. https://doi.org/10.1016/j.ajhg.2019.06.006

Shapiro, N. T., Hippe, D. S., & Ram, írez N. F. (2021). How Chatty Are Daddies? An Exploratory Study of Infants' Language Environments. *Journal of Speech, Language, and Hearing Research*, *64*(8), 3242–3252. https://doi.org/10.1044/2021_JSLHR-20-00727

Shavlik, M., Davis-Kean, P. E., Schwab, J. F., & Booth, A. E. (2021). Early word-learning skills: A missing link in understanding the vocabulary gap? *Developmental Science*, *24*(2), e13034. https://doi.org/10.1111/desc.13034

Snelbaker, A. J., Wilkinson, G. S., Robertson, G. J., & Glutting, J. J. (2001). Wide Range Achievement Test 3 (wrat3). In W. I. Dorfman & M. Hersen (Eds.), *Understanding Psychological Assessment* (pp. 259–274). Springer US. https://doi.org/10.1007/978-1-4615-1185-4_13

Spencer, S., Clegg, J., & Stackhouse, J. (2013). Language, social class and education: Listening to adolescents' perceptions. *Language and Education*, *27*(2), 129–143. https://doi.org/10.1080/09500782.2012.760585

Sperry, D. E., Sperry, L. L., & Miller, P. J. (2019). Language Does Matter: But There is More to Language Than Vocabulary and Directed Speech. *Child Development*, *90*(3), 993–997. https://doi.org/10.1111/cdev.13125

Starr, A., Haider, Z. F., & von Stumm, S. (2024). Do school grades matter for growing up? Testing the predictive validity of school performance for outcomes in emerging adulthood. *Developmental Psychology*, *60*(4), 665–679. https://doi.org/10.1037/dev0001548

Starr, A., Oginni, O., & von Stumm, S. (2024). Do Children Cause the Cognitive Stimulation they Receive? Modelling the Direction of Causality. *Behavior Genetics*. https://doi.org/10.1007/s10519-024-10195-w

Starr, A., Ruks, M., Giannelis, A., Willoughby, E., Pettersson, O., Pahnke, C. K. L., Maj, C., Andreas, A., Ahlskog, R., Arseneault, L., Fisher, H. L., Forstner, A. J., Kandler, C., McGue, M., Nöthen, M. M., Oskarsson, S., Spinath, F. M., Vrieze, S., Wertz, J., & von Stumm, S. (2025). Within- and between-family genetic effects on educational achievement vary across countries and ages. *Molecular Psychiatry.* https://doi.org/10.1038/s41380-025-03342-0

Stern, D. N., Spieker, S., Barnett, R. K., & MacKain, K. (1983). The prosody of maternal speech: Infant age and context related changes. *Journal of Child Language*, *10*(1), 1–15. https://doi.org/10.1017/s0305000900005092

Stopforth, S., Gayle, V., & Boeren, E. (2021). Parental social class and school GCSE outcomes: Two decades of evidence from UK household panel surveys. *Contemporary Social Science*. https://www.tandfonline.com/doi/abs/10.1080/21582041.2020.1792967

Stromswold, K. (2001). The Heritability of Language: A Review and Metaanalysis of Twin, Adoption, and Linkage Studies. *Language*, *77*(4), 647–723.

Sullivan, O. (2021). *Chapter 21: The gender division of housework and child care*. https://www.elgaronline.com/edcollchap-oa/edcoll/9781788975537/9781788975537.00033.xml

Tarar, J. M., Meisinger, E. B., & Dickens, R. H. (2015). *Test review: Test of Word Reading Efficiency–Second Edition (TOWRE-2) by Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. Canadian Journal of School Psychology, 30*(4), 320–326. https://doi.org/10.1177/0829573515594334

Thorpe, K. (2006). Twin children's language development. *Early Human Development*, *82*(6), 387–395. https://doi.org/10.1016/J.EARLHUMDEV.2006.03.012

Torgesen, J. K., Rashotte, C. A., & Wagner, R. K. (1999). *TOWRE: Test of word reading efficiency*. Pro-ed Austin, TX.

Trouton, A., Spinath, F. M., & Plomin, R. (2002). Twins early development study (TEDS): A multivariate, longitudinal genetic investigation of language, cognition and behavior problems in childhood. *Twin Research: The Official Journal of the International*

Society for Twin Studies, *5*(5), 444–448. https://doi.org/10.1375/136905202320906255

Tubeuf, S., & Jusot, F. (2011). Social health inequalities among older Europeans: The contribution of social and family background. *The European Journal of Health Economics*, *12*(1), 61–77. https://doi.org/10.1007/s10198-010-0229-3

Uccelli, P. (2023). The Language Demands of Analytical Reading and Writing at School. *Written Communication*, *40*(2), 518–554. https://doi.org/10.1177/07410883221148727

Uccelli, P., Galloway, E. P., Barr, C. D., Meneses, A., & Dobbs, C. L. (2015). Beyond Vocabulary: Exploring Cross-Disciplinary Academic-Language Proficiency and Its Association With Reading Comprehension. *Reading Research Quarterly*, *50*(3), 337–356. https://doi.org/10.1002/rrq.104

Vadivel, B., Alam, S., Nikpoo, I., & Ajanil, B. (2023). The Impact of Low Socioeconomic Background on a Child's Educational Achievements. *Education Research International*, *2023*(1), 6565088. https://doi.org/10.1155/2023/6565088

van der Erve, L., Krutikova, S., Macmillan, L., & Sturrock, D. (2023). *Intergenerational mobility in the UK*. Institute for Fiscal Studies. https://ifs.org.uk/inequality/intergenerational-mobility-in-the-uk/

van der Veen, C., & van Oers, B. (2017). Advances in research on classroom dialogue: Learning outcomes and assessments. *Learning and Instruction*, *48*, 1–4. https://doi.org/10.1016/j.learninstruc.2017.04.002

Verhoef, E., Allegrini, A. G., Jansen, P. R., Lange, K., Wang, C. A., Morgan, A. T., Ahluwalia, T. S., Symeonides, C., Andreassen, O. A., Bartels, M., Boomsma, D., Dale, P. S., Ehli, E., Fernandez-Orth, D., Guxens, M., Hakulinen, C., Harris, K. M., Haworth, S., de Hoyos, L., … St. Pourcain, B. (2024). Genome-Wide Analyses of Vocabulary Size in Infancy and Toddlerhood: Associations With Attention-Deficit/Hyperactivity Disorder, Literacy, and Cognition-Related Traits. *Biological Psychiatry*, *95*(9), 859–869. https://doi.org/10.1016/j.biopsych.2023.11.025

Visscher, P. M. (2008). Sizing up human height variation. *Nature Genetics*, *40*(5), 489–490. https://doi.org/10.1038/ng0508-489

von Stumm, S. (2017). Socioeconomic status amplifies the achievement gap throughout compulsory education independent of intelligence. *Intelligence*, *60*, 57–62. https://doi.org/10.1016/j.intell.2016.11.006

von Stumm, S. (2024). Early childhood inequalities: The rocky path from observation to action. *Oxford Open Economics*, *3*(Supplement_1), i754–i757. https://doi.org/10.1093/ooec/odad070

von Stumm, S., Arseneault, L., Caspi, A., Ph.D., Fisher, H. L., Moffitt, T., Sugden, K., … Brown, A. (2025). The role of the 'word gap' in educational inequality: A genetically sensitive study. *Preprint:* https://doi.org/10.31234/osf.io/6ec5r_v1

von Stumm, S., Cave, S. N., & Wakeling, P. (2022). Persistent association between family socioeconomic status and primary school performance in Britain over 95 years. *Npj Science of Learning*, *7*(1), 1–8. https://doi.org/10.1038/s41539-022-00120-3

von Stumm, S., & d'Apice, K. (2022). From Genome-Wide to Environment-Wide: Capturing the Environome. *Perspectives on Psychological Science*, *17*(1), 30–40. https://doi.org/10.1177/1745691620979803

von Stumm, S., O'Reilly, J., & d'Apice, K. (2022). Predicting developmental outcomes in middle childhood from early life language and parenting experiences. *British Journal of Developmental Psychology*, *40*(4), 487–503. https://doi.org/10.1111/bjdp.12427

Wade, M., Jenkins, J. M., Venkadasalam, V. P., Binnoon-Erez, N., & Ganea, P. A. (2018). The role of maternal responsiveness and linguistic input in pre-academic skill development: A longitudinal analysis of pathways. *Cognitive Development*, *45*, 125–140. https://doi.org/10.1016/j.cogdev.2018.01.005

Wainschtein, P., Zhang, Y., Schwartzentruber, J., Kassam, I., Sidorenko, J., Fiziev, P. P., Wang, H., McRae, J., Border, R., Zaitlen, N., Sankararaman, S., Goddard, M. E., Zeng, J., Visscher, P. M., Farh, K. K.-H., & Yengo, L. (2025). Estimation and mapping of the missing heritability of human phenotypes. *Nature*, https://doi.org/10.1038/s41586-025-09720-6

Walthery, P., & Chung, H. (2021). *Sharing of childcare and wellbeing outcomes: An empirical analysis*.

Webbink, D., Posthuma, D., Boomsma, D. I., Geus, E. J. C. de, & Visscher, P. M. (2008). Do twins have lower cognitive ability than singletons? *Intelligence*, *36*(6), 539–547. https://doi.org/10.1016/J.INTELL.2007.12.002

Wechsler, D. (1989). Wechsler preschool and primary scale of intelligence—Revised. *Journal of School Psychology*.

Weizman, Z. O., & Snow, C. E. (2001). Lexical output as related to children's vocabulary acquisition: Effects of sophisticated exposure and support for meaning. *Developmental Psychology*, *37*(2), 265–279. https://doi.org/10.1037/0012-1649.37.2.265

Wertz, J., Belsky, J., Moffitt, T. E., Belsky, D. W., Harrington, H., Avinun, R., Poulton, R., Ramrakha, S., & Caspi, A. (2019). Genetics of nurture: A test of the hypothesis that parents' genetics predict their observed caregiving. *Developmental Psychology*, *55*(7), 1461. https://doi.org/10.1037/dev0000709

Wertz, J., Moffitt, T. E., Agnew-Blais, J., Arseneault, L., Belsky, D. W., Corcoran, D. L., Houts, R., Matthews, T., Prinz, J. A., Richmond-Rakerd, L. S., Sugden, K., Williams, B., & Caspi, A. (2020). Using DNA from mothers and children to study parental investment in children's educational attainment. *Child Development*, *91*(5), 1745–1761. https://doi.org/10.1111/cdev.13329

Wilding, K., Wright, M., & von Stumm, S. (2024). Using DNA to Predict Education: A Meta-analytic Review. *Educational Psychology Review*, *36*(4), 102. https://doi.org/10.1007/s10648-024-09928-4

Wilkinson, R. G., & Pickett, K. E. (2007). The problems of relative deprivation: Why some societies do better than others. *Social Science & Medicine*, *65*(9), 1965–1978. https://doi.org/10.1016/j.socscimed.2007.05.041

Wood, E., Brown, A., & von Stumm, S. (2026). Twins and their singleton siblings differ in cognition, language, and social-emotional development. *Child Development, accepted.* Preprint: https://osf.io/vp83n

Young, A. I. (2019). Solving the missing heritability problem. *PLOS Genetics*, *15*(6), e1008222. https://doi.org/10.1371/journal.pgen.1008222

Zhao, X., Lynch Jr., J. G., & Chen, Q. (2010). Reconsidering Baron and Kenny: Myths and truths about mediation analysis. *Journal of Consumer Research*, *37*(2), 197–206. https://doi.org/10.1086/651257

The role of mothers' speech in the transmission of family background inequality