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Longitudinal associations between socioeconomic status and executive function during adolescence: Evidence from the SCAMP study

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ABSTRACT

Few studies have isolated associations between socioeconomic status (SES) and executive function (EF) in adolescence, when EF inequalities may be particularly consequential for academic attainment. Using data from the Study of Cognition, Adolescents and Mobile Phones ($n = 2726$) and multiple regressions, we evaluated relationships between SES indices (parental education and occupation, area-level deprivation, and household poverty) and EF tasks, controlling for demographic factors. Replicating findings from childhood, latent SES and EF measures associated cross-sectionally at age 12 ($\beta = 0.11$, [0.07, 0.15]). We further observed a small increase in the socioeconomic EF gradient between 12 and 14 years ($\beta = 0.07$, [0.04, 0.11]), with which was specifically associated with parental occupation and household poverty. Working memory span tasks were particularly sensitive to SES. Our results highlight specific SES-EF associations during adolescence and could help identify pupils at risk for cognitive, and therefore academic, challenges who may benefit from targeted support.

Educational relevance and implications: Individual differences in EF skills associate with educational outcomes across development, as well as health and occupational outcomes in adulthood. This study demonstrates that, in a UK sample, SES not only associates with individual differences in EF in childhood, but that over a period as short as two years, parental occupation and household poverty (but not parental education or area deprivation), associate with small but significant increasing differences in adolescents' working memory skills. By isolating specific associations between aspects of SES and EF inequalities, this study suggests family level factors have an enduring influence on cognitive skills into adolescence, which may contribute to the trend of increasing attainment inequalities seen in this age group. The findings help to narrow the pool of likely causal explanations for social inequalities in EF skills and may help to identify pupils who are at risk for cognitive, and therefore academic, challenges.

1. Introduction

Executive functions (EFs) are a set of cognitive processes that enable the production of goal-directed, non-automatic behaviours (Miyake et al., 2000). They allow individuals to flexibly navigate through life by conscious planning and strategising. Hence, these skills associate with a host of educational, health, and occupational outcomes (Ahmed et al., 2019; Diamond, 2013; Galioto et al., 2018; Letkiewicz et al., 2014). Globally, a small to moderate socioeconomic gradient in EF is seen within countries whereby children from deprived backgrounds score lower on measures of EF than their peers (Lawson et al., 2018). EF inequalities partly mediate the association between SES and attainment (Ding et al., 2024) and are likely to be particularly consequential during adolescence, where low attainment limits an individual's higher education and career opportunities. However, little is known about the specificity of the association between markers of SES and EF, or about the relationship between SES and EF, in adolescence.

SES, the relative disparity between individuals in terms of access to

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resources and opportunities (e.g., Destin et al., 2012; Moya & Fiske, 2017; Ross & Mirowsky, 2008), is a multifaceted construct which can be operationalised in a number of different ways. Studies tend to use composite SES indices or focus on a single aspect of SES, typically parental education level or household income, with fewer studies focusing on parental occupation (Lawson et al., 2018). These factors tend not to show correlations greater than $r = 0.5$ with one another (Farah, 2017) and are likely to index different mechanisms through which SES might influence cognitive development. Bukodi and Goldthorpe (2013) suggest that parental education can be viewed a marker for educational resources, including learning resources in the home and capacity to support the child with their learning and in navigating the education system. When different SES indices are modelled together, Bukodi and Goldthorpe (2013) suggest that parental occupation indexes sociocultural resources (e.g., social networks, parental and cultural values and expectations, engagement with culturally enriching activities), linking this to the concept of social class, and that household income acts a marker of financially determined resources (e.g., nutrition pre- and post-natally, extra-curricular activities and tutoring). Using data from the British Birth Cohort Study, Schoon et al. (2021) showed that parental education, parental occupation and household income all explained unique variance in child cognitive skills. These results demonstrate how focusing on the same few individual-level indices of SES may not adequately capture the complexity or the full extent of the relationship between SES and EF.

Several recent neuroimaging studies have additionally highlighted the potential significance of often overlooked neighbourhood level SES factors which may index access to services (e.g., healthcare, high quality schools; Shucksmith et al., 2023) as well as exposure to pollutants (e.g., lead, noise, pesticide and other neurotoxins; Herting et al., 2019; Thomas & Coecke, 2023). A large scale study of 8–23 year-olds from Philadelphia showed that area-level deprivation, measured as a weighted factor score of census-derived data (e.g., median family income, percent people in poverty, percent of residents who are married) in the local area, was associated with lower activation of fronto-parietal task-relevant brain regions during a 2-back task, including when controlling for parental education (Murtha et al., 2022). Rakesh et al. (2021) have documented more widespread alterations in brain activity that appear to be linked to area-level deprivation in another US sample, aged 9–11 years. Neighbourhood deprivation was related to lower between- and within-network resting state functional connectivity in sensorimotor and higher-order networks (e.g., default mode; dorsal attention), and these differences in connectivity were significantly predictive of EF task performance, measured by a baseline cognitive task battery. Area-level deprivation may therefore be a dimension of SES with important consequences for EF development, in addition to parental education, income and occupation. As both studies were cross-sectional, further evidence is needed to determine *when* area-level deprivation may be meaningfully related to EF development.

Some possible mechanisms through which SES might affect cognitive development would be expected to impact the development of the whole brain (Johnson et al., 2021), e.g., diet (Verstynen et al., 2012). By contrast, it has recently been argued that adverse experiences during development, such as growing up in poverty, should selectively impact specific cognitive skills; skills that are relevant to functioning in one's environment may be heightened whilst others may be negatively impacted through mechanisms such as chronic stress or lack of cognitive stimulation (e.g., by Amir et al., 2018; Frankenhuis & Nettle, 2020; Mittal et al., 2015). Specifically, there is some evidence that skills that help individuals growing up in adversity to cope with high levels of uncertainty (e.g., being able to rapidly shift attention) are a relative strength for disadvantaged individuals (Mittal et al., 2015). A better understanding of the specificity or generality of associations between SES and EF would inform the choice of targets for interventions trying to mitigate the downstream consequences of SES on educational outcomes.

Studies have predominantly focused on SES associations with cognitive development in early childhood despite evidence indicating that EF skills, and the brain regions supporting EF, continue maturing into the early 20s (Huizinga et al., 2006; Simmonds et al., 2017). Early adolescence represents the most rapid period of cognitive development after infancy and has therefore been referred to as a second window of vulnerability/opportunity (Fuhrmann et al., 2015). EF skills show rapid development during early adolescence (Ahmed et al., 2022) and may therefore be particularly sensitive to environmental influences during this period. Further, since adolescence is characterised by heightened social comparison and increased autonomy (Choudhury et al., 2023), existing inequalities in cognitive skills may be exacerbated by the decisions that young people make. For example, it has been suggested that a process of disillusionment with education occurs for low SES pupils during adolescence. They are thought to reduce the effort they put into schoolwork as they become cognisant of SES-linked differences in access to opportunities and come to understand the substantial cost of entering into higher education (Caro et al., 2009; Guo, 1998), compounding the pre-existing inequalities between them and their more affluent peers in terms of exposure to cognitively stimulating activities. Adolescence is both a distinct developmental stage in terms of EF and a time where social and academic pressures are heightened relative to earlier in childhood.

Lawson et al.'s (2018) meta-analysis suggests that general associations between SES and EF may be more likely than specific associations, at least in childhood (only 2/33 studies involved adolescents). Studies using composite measures of EF showed the largest SES effect sizes ($r = 0.28$), followed by working memory (WM) measures, attention shifting, inhibitory control (IC), and other abilities such as planning. Convergent results in predominantly childhood samples were reported by Tucker-Drob (2013), who found that parental education level had non-specific relationships with different cognitive measures and by Bignardi et al. (2024), who found a moderate association between an SES composite and general cognitive ability using data from three cohort studies, whilst associations with specific EF measures were mostly small and non-significant or inconsistent across cohorts. However, Lawson et al. note that stronger general associations could have been observed because composite measures are more reliable than individual EF measures in young children. The more psychometrically robust EF measures available for adolescents may allow a better differentiation of specific vs. general SES – EF associations.

Adolescents may also show greater specificity of SES–EF associations than children as EFs become more differentiated over the course of adolescence (Karr et al., 2018; Lee et al., 2013). Moreover, since SES tends to remain stable (Hackman et al., 2015), by adolescence there may be a cumulative effect of familial relative socioeconomic standing, making the effects of factors related to different aspects of SES more pronounced. Finally, different aspects of SES may also differentially affect EF development during childhood compared to adolescence. During adolescence, the influence of parents relative to peers on decision making decreases (Icenogle & Cauffman, 2021), so SES factors outside of the family could potentially become more important at this stage.

Different aspects of SES tend to correlate and therefore explain shared variance in developmental outcomes, so multiple aspects of SES need to be modelled together to identify specific associations. To date, only three published studies (Donati, Dumontheil, & Meaburn, 2019; Madhushanthi et al., 2020; Sutin et al., 2022) have modelled together multiple SES and/or EF indicators when exploring SES-EF associations during adolescence (see Table 1 for details of these studies). Across studies, aspects of family level SES were significant predictors of EF and in all studies WM skills were identified as being sensitive to SES in adolescence with effect sizes up to $r = 0.29$ reported. However, they provide inconsistent evidence regarding the sensitivity of inhibitory control to SES, with both Donati et al. and Madhushanthi et al. testing its association with parental occupation and reporting effect sizes different by a magnitude of nearly 3×. Any further comparisons between these

Table 1
Description of the study design and results of three previous studies of specific SES-EF associations.

	Donati et al. (2019)	Madhushanthi et al. (2020)	Sutin et al. (2022)
Location	Southwest England	Galle Sri Lanka	Australia-wide
Design	Longitudinal	Cross-sectional	Longitudinal
Sample size	5838 (with imputation)	200	4164 (with imputation)
Sex	52 % females	Females only	48.8 % females
SES	measured at 0–8 years	measured at 11–14 years	measured at 10–11 years
EF	measured at 10–17 years	measured at 11–14 years	measured at 15 years
Parent education	N/A	βWM = 0.26 βIC = −0.13 (n.s.)	A composite of these indices positively predicted attention and error monitoring but not WM.†
Parent occupation	*r*WM = 0.29 *r*IC = −0.07	βWM = 0.09 (n.s.) βIC = −0.20 (n.s.)	
Household income	N/A	βWM = −0.02 (n.s.) βIC = −0.09 (n.s.)	
Area deprivation	N/A	N/A	Positively predicted WM and attention but not error monitoring.†

Notes. WM: working memory; IC: inhibitory control.
† No standardised effect sizes were reported in this study.

studies in terms of specific SES-EF associations are difficult to draw due to differences in design and SES and EF measures employed.

Unlike Donati et al. (2019) and Sutin et al. (2022), Madhushanthi et al. (2020) looked at associations between individual SES indices and EF, holding other aspects of SES constant. Their results may therefore give a clearer indication of the unique contributions of different aspects of SES to EF, whereas SES effects in the other studies may be partially explained by the associations of these measures with other, non-modelled, aspects of SES. However, Madhushanthi et al. did not control for area deprivation, so the family level SES effects they occur may be picking up on neighbourhood factors. To our knowledge, no previous studies of child or adolescent samples have simultaneously modelled the associations of parental education, income, and occupation and area deprivation with EF, so it is not clear which aspects of family level SES (if any) predict EF controlling for area deprivation and whether area deprivation predicts EF controlling for family level SES.

Importantly, despite there being a lag between SES and EF measurement in Sutin et al. (2022) and Donati et al. (2019), none of these studies isolate SES effects that unfold specifically during adolescence by including a late childhood measure of EF. Longitudinal (baseline corrected) studies with a comprehensive set of SES indicators are needed to advance our understanding of the precise nature of SES-EF associations during adolescence. Given the substantial concurrent associations between SES and EF, studies that look at time 1 SES as a predictor of time 2 EF without time 1 EF measures may also simply be picking up on EF-EF or SES-SES associations. Baseline corrected (or cognitive change) studies can also help to rule out this possibility.

Here we used SES and longitudinal cognitive data from the UK Study of Cognition, Adolescents and Mobile Phones (SCAMP; Toledano et al., 2018; https://scampstudy.org/), to explore the relative predictive power of different indices of SES (parental education, parental occupation, area level deprivation, income poverty) for specific EF outcomes. We predicted that SES would significantly associate with EF cross-sectionally in early adolescence (10–13 years, H1) and longitudinally (13–15 years), controlling for EF at 10–13 years (H2). We further predicted that different SES indices would show some specific associations with EF during adolescence, and that SES may differentially associate with specific EFs (H3i). We did not make any predictions about the nature of specific associations, given the limited and inconsistent research done with this age group and our SES indices (Table 1). However, we expected to observe evidence to support the notion that SES-EF relations during adolescence are specific rather than general (H3ii), since EFs are thought to become more differentiated through adolescence.

Since only single measures of shifting and inhibition were completed in SCAMP, we were not able to employ a comprehensive latent variable approach so models testing the sensitivity of different aspects of EF to SES focused on performance on individual EF tasks. SES-EF associations were compared with associations between SES and more general measures of cognition, namely non-verbal reasoning and language ability, which have both been shown to associate with SES in childhood (e.g., Piccolo et al., 2016).

2. Methods

2.1. Ethics

The original SCAMP study protocol and subsequent amendments were approved by The North West-Haydock Research Ethics Committee. Ethical approval for the linkage of SCAMP data with National Pupil Database data for the purposes of RCP's PhD project was granted by the Imperial College London Research Ethics Committee (Protocol number 14IC2067, version 4, 29/07/2014).

2.2. Participants

This study included 2726 secondary school pupils (54 % female) from the SCAMP study. SCAMP is a longitudinal cohort study ($N = 6905$) which followed adolescents, recruited from the Greater London area in the UK, through secondary education. It involved the completion of a battery of cognitive and demographic measures at two time points during early to mid-adolescence. These data have been linked with school records from the National Pupil Database. Time 1 (T1) data were collected in 2014–2016 when participants were in Year 7 (age range 10.4–13.5 years, $M = 12.06$, $SD = 0.38$), and time 2 (T2) data were collected in 2016–2018 when participants were in Year 9/10 (age range 13.0–16.0, $M = 14.29$, $SD = 0.48$). Please see **Supplemental Materials** and **Supplementary Fig. S1** for an explanation of the exclusion criteria for the present study. Tasks were completed in a fixed order so, due to time constraints and differences in completion speed between participants, the number of participants differs for each task. Some demographic information was also missing as this was acquired through optional self-report. Table 2 summarises demographic information for the sample included in our analyses and a comparison with the statistics for the London region and for England (where available; see Toledano et al., 2018 and **Supplementary Materials Table S1** for information on the complete cohort).

Compared to national figures, the sample included in the analyses had a smaller proportion of participants who were white or had English as their first language, a higher proportion of parents who had attended university, a skew towards higher occupations (note we took the highest occupation of the two parents in our sample), lower area level deprivation, and a comparable proportion of free school meal recipients. This reflects, in part, differences between the London region and England as a whole.

2.3. Measures

Cognitive tasks and questionnaires were designed and completed through Psytools software (Delosis Ltd.; https://www.delosis.com/psytools/) as a whole class during the participants' IT lessons in their school computer suites. Tasks which are generally administered as pen

Table 2
Demographics of the included sample compared to regional and national figures.

	SCAMP subsample	*London figures*	*England figures*
First language	2713		
English	1483 (55 %)	60 %[a]	85 %[a]
English learnt at the same time as another language	674 (25 %)	39 %	15 %
Not English	556 (20 %)		
Ethnicity	2726		
White (British, Irish, other)	904 (33 %)	40 %[a]	76 %[a]
Black (Caribbean, African, other)	477 (17 %)	21 %	5 %
Asian (Indian, Pakistani, Bangladeshi, Chinese, other)	822 (30 %)	22 %	11 %
Any mixed race	310 (11 %)	9 %	5 %
Other ethnic group or unclassified[†]	213 (8 %)	8 %	3 %
Number of university educated parents	1934		
0	730 (38 %)	60 % of individuals >16 years are university educated[b]	38 % of individuals >16 years are university educated[b]
1	443 (23 %)		
2	761 (39 %)		
Parent highest occupation	2335		
0 - Never worked and long-term unemployed	0 (0 %)	11 %[b]	9 %[b]
1 - Routine occupations	91 (4 %)	10 %	12 %
2 - Semi-routine occupations	248 (11 %)	10 %	11 %
3 - Lower supervisory & technical occupations	146 (6 %)	4 %	5 %
4 - Small employers & own account workers	456 (20 %)	12 %	11 %
5 - Intermediate occupations	227 (10 %)	11 %	11 %
6 - Lower managerial, administrative & professional occupations	459 (20 %)	23 %	20 %
7 - Higher professional occupations	555 (24 %)	19 %	13 %
8 - Large employers, higher managerial & administrative occupations	153 (7 %)		
Area-level deprivation	2651		
1 – least deprived	156 (6 %)	20 %[c]	20 %[c]
2	330 (12 %)	20 %	20 %
3	442 (17 %)	20 %	20 %
4	664 (25 %)	20 %	20 %
5 – most deprived	1059 (40 %)	20 %	20 %
Free school meals status	2617		
Eligible	493 (19 %)	18 %[a]	13 %[a]
Not eligible	2124 (81 %)	82 %	87 %

Notes. Percentages are expressed as the proportion of included participants with data for that measure that belong to a given category. Ethnicity classifications are based on the UK Office for National Statistics classification system: https://www.ons.gov.uk/methodology/classificationsandstandards/measuringequality/ethnicgroupnationalidentityandreligion.

[†] Other/unclassified ethnicity was not included in the models due to low counts and because we take ethnicity to be a measure of cultural background and "other" is unlikely to represent a homogenous group of students.

[a] Secondary state school pupils in January 2016 (GOV.UK, 2016).

[b] 2021 Census data on all adults aged over 16 (Office for National Statistics, 2022).

[c] The expected distribution for area-level deprivation is 20 % in each category as the index divides the region of interest into quintiles.

and paper measures were adapted to be run on computers (see Toledano et al., 2018 for details of the complete task and questionnaire battery). Data on Free School Meals status and Key Stage 2 Reading Standardised Assessment Tests (SATs) were obtained from the UK Department for Education's National Pupil Database.

2.3.1. *Cognitive measures*

The cognitive tasks are briefly described below. They were included in the SCAMP battery as they are developmentally appropriate for the age group studied. The original versions of all measures have been demonstrated to show adequate to excellent psychometric properties (e.g., see Bailey et al., 2018; Bombin et al., 2013; Cattell et al., 1960; Cooper & Stewart, 2017; Karlsen et al., 2022).While the presentation of the Backwards Digit Span task and Corsi span task were adapted for computerised assessment and use a staircase adaptive design to reduce testing time, the correlations between these tasks and between these tasks and the CFT, as a proxy for IQ, are on par with those observed with a more standard testing format (e.g. Morris et al., 2019). For more details, on the measures used please see Filippi et al. (2022) and for example stimuli see **Supplemental Material Figs. S3** and **S4**.

2.3.1.1. Trail-making test (TMT). A version of the TMT (Adjutant General's Office, 1944) measured cognitive flexibility. In the letters condition, dots were labelled with letters and participants had to click them in alphabetical order. In the switching condition, dots were labelled with a number or a letter and participants were required to click these in alternating alphabetical and numerical sequences. The measure of task performance is the residual of the time to complete the numbers/letters condition after covarying the time to complete the letters condition. This measure reflects relative response time on the switching block compared to the single sequence block, a higher value reflects a greater switch cost.

2.3.1.2. Backward digit span (BDS). Verbal WM was measured with a variant of the BDS task (Dumontheil & Klingberg, 2012). Single digit numbers were presented visually individually, participants were required to reproduce the number sequence in reverse order using a numerical response pad displayed on screen. Sequence length could vary between 2 and 9 and was increased or decreased incrementally following the staircase/Levitt procedure (Levitt, 1971). The measure on this task was the average of the mean sequence length of trials with a correct response and the mean sequence length of trials with an incorrect response.

2.3.1.3. Spatial working memory task (SWM). The SWM was used to measure spatial WM and planning and was adapted from the Cambridge Neuropsychological Testing Automated Battery (Luciana & Nelson, 2002) task of the same name. The task required participants to click on ringing telephones to answer them. Participants had to work out which phone was ringing at a given time and answer that phone, while recalling which ones had already rung to avoid selecting the same phone twice. Four levels played out in ascending order of difficulty (4, 6, 8, then 10 phones). Measures were the total number of errors and a strategy score, which reflects planning and is the number of excess switches of the starting location on each search at levels 6, 8 and 10 (this is based on the assumption that starting the search in the same location on each trial, except if this phone has already rung, would aid performance and reflect planning). A higher strategy score reflects a less efficient strategy.

2.3.1.4. Corsi block tapping task. An additional measure of visuo-spatial WM was a computerised version of the Corsi task, similar to the task used by Dumontheil and Klingberg (2012). Participants saw a 4 × 4 grid of 16 circles which lit up individually in a pseudo-randomised sequence and were asked to reproduce the sequence by clicking the circles in the same order in an empty array. The number of dots changed in a staircase fashion and the performance measure was calculated in the same way as for the BDS task.

2.3.1.5. AX-continuous performance task (CPT). An adapted form of Brocki and Bohlin's (2004) AX-CPT was used. On each trial, the letters "A", "B", "C", "D", or "X" were presented and participants were asked to respond with a key press if an X followed an A. The test phase comprised 54 trials, with 9 targets. A range of different error types can be considered on this task. As the number of trials and the number of errors were low, the key measure was the total number of errors, i.e., the sum of omission errors (not pressing when an X followed an A) and the number of commission errors (pressing for a sequence other than A–X), which reflects inattention, impulsivity, and disinhibition.

2.3.1.6. Cattel's culture fair test (CFT). We used stimuli from the Cattel's Culture Fair Test (Cattell et al., 1960) Form A, Scale 2 as a measure of non-verbal reasoning, specifically the Odd One Out and Complete the Pattern subtests. Participants had three minutes for each task to complete as many trials as possible (up to 14 for Odd One Out; up to 11 for Complete the Pattern). The measure on this task was the total number of correct trials on the two subtests.

2.3.1.7. Reading SAT. All British pupils educated in state funded primary schools take SATs in the summer of their final year of primary school (Year 6; age 11). We used participants' reading SAT score as our measure of language skills (scale = 3–6).

2.3.2. SES indices

2.3.2.1. Number of parents who attended university. We created a total number of parents who attended university variable (0, 1 or 2; see **Supplemental Materials** for details).

2.3.2.2. Parental highest occupation. Pupils' reports on the occupations of their parents were translated into an occupational prestige ranking for each of the pupil's parents, with possible ratings from 0 to 8 based on the Office for National Statistics (2010) classification system. We took the highest occupation classification of the pupil's parents as the index.

2.3.2.3. Area-level deprivation. We calculated relative area-level deprivation according to the Carstairs's Index (Carstairs & Morris, 1990) using pupils' postcodes. The index used 2011 Census data to calculate an area's relative deprivation level on a scale of 1 to 5 (quintile 1 being least deprived), considering the proportion of male unemployment, lack of car ownership, overcrowding, and head of households in low occupational classes in an area.

2.3.2.4. Free school meals (FSM) status. Eligibility to free school meals in Year 7 (age 11–12) (yes/no) was used as a measure of household poverty.

2.4. Analysis

We excluded extreme outliers for the EF tasks and Culture Fair Test (CFT), defined as scores ±3.29 *SD*s from the mean score on a given cognitive test, a range that should include 99.9 % of normally distributed data (Field, 2009). This resulted in the exclusion of the following number of datapoints: Trail Making Test (TMT), T1: 26, T2: 32; Backwards Digit Span (BDS), T1: 7, T2: 4; SWM errors, T1: 7, T2: 8; SWM strategy, T1: 4, T2: 2; Corsi: T1: 2, T2: 0; Continuous Performance Test (CPT): T1: 12, T2: 8; CFT, T1: 2, T2: 5.

A linear modelling approach was adopted as is typical in this research area (e.g., Madhushanthi et al., 2020; Pluck et al., 2021; Sutin et al., 2022), since SES associations with cognitive skills are observable across the entire SES distribution (see Rosen et al., 2019 for a review) and since categorical treatment of the SES indices did not improve model fit (**Table S2**). lavaan's (version 0.6–15) sem() function with full information maximum likelihood (FIML) estimation was used for all analyses. FIML uses all available data in parameter estimation, maximising power relative to deletion methods. Please see **Supplementary Materials** and **Fig. S2** for details on the patterns of missingness in this dataset.

We used Huber-White estimated robust standard errors to correct for violations of homoscedasticity assumptions and correlations in the data due to cluster sampling. We took this approach as we were only interested in correcting for the inflation of type 1 errors and because school effects were not directly related to the research questions (McNeish, 2023). Multilevel modelling was not appropriate as estimation issues are common when applied to datasets with <30 clusters. Also, some clusters contained very few participants and therefore no to low within-cluster variance in SES and attainment so fixed effect modelling was not appropriate (see McNeish & Kelley, 2019).

Highest parental occupation (coded as 0–8), how many of the pupil's parents attended university (0, 1, or 2), and area-level deprivation (coded as 1–5) were treated as continuous variables as (i) solutions for models with continuous predictors are easier to interpret (Long & Freese, 2006), (ii) models treating ordinal variables as continuous rarely fail to identify effects that would be observable if the variable was treated as ordinal (Pasta, 2009), and (iii) comparing univariate regression models where SES indices were treated as categorical versus continuous did not show significantly better fit.

To test for generality versus specificity of associations, T1 SES, and T1 EF and T2 EF latent factors were created using confirmatory factor analysis (CFA).

We controlled for age, ethnicity (as a marker of cultural background; white/black/Asian/mixed), first language status (English learnt first/English learnt at the same time as another language/English not the first language learnt), and self-reported gender (male/female) in all models. We included age as EF skills continue to improve during adolescence (Huizinga et al., 2006) and lag time in longitudinal models as there were differences between schools in terms of the gap between the two assessments due to scheduling constraints (range = 8 months – 4 years, 4 months). We controlled for ethnicity and first language status as these are correlated with SES and EF and we wanted to rule out the possibility that these factors were driving any SES-EF associations (Engel de Abreu et al., 2012; Filippi et al., 2022; GOV.UK, 2018; Rea-Sandin et al., 2021). Finally, since gender correlated with SES in the SCAMP cohort (Table 4), and since there is evidence that gender may predict different cognitive developmental trajectories (Grissom & Reyes, 2019), we adjusted for its influence on EF skills to allow for a clear picture of how our SES variables of interest associated with EF. In supplementary analyses (**Supplementary Tables S7-S8**), we additionally controlled for school quality to test whether our findings might be explained by higher SES students attending higher quality schools.

Davis-Kean and Sexton (2009) showed that ethnicity moderates the association between family characteristics and attainment, but we found little evidence to suggest that this was true for SES-EF relations in this sample (see **Supplementary Materials Figs. S5a-b** and **S6**) so we did not split by ethnicity. Positive associations between SES and EF were seen in all ethnicity groups although these were attenuated in groups representing lower diversity in SES.

Regression analyses were repeated using non-verbal reasoning and reading SAT as outcome variables for comparison. Cross-sectional analyses were carried out on the T1 data, while longitudinal analyses assessed associations in adolescence, controlling for the impact of SES on cognition in childhood by including the T1 factor/measure in the regression equations.

3. Results

3.1. Descriptives

Table 3 shows the sample size and average scores on each measure at T1 and at T2. Paired *t*-tests indicated that pupils performed significantly better on all EF measures and non-verbal reasoning at T2. T1 and T2 measures on each task showed positive parametric correlations that were mostly above 0.30, except for the TMT switch cost and SWM strategy measures, suggesting these two measures may be less reliable.

3.2. Correlation analyses

CFAs were carried out to construct an SES latent factor at T1 and EF latent factors at T1 and T2 (see **Supplemental Materials Fig. S7**). Table 4 shows the cross-sectional correlations between all the variables of interest at T1, while Table 5 shows the longitudinal correlations between T1 predictors/controls and T2 outcome variables and **Supplemental Materials Tables S3-S4** show the correlations between dummy coded control variables and SES and EF measures. The strongest correlations tended to be between SES measures, and between EF measures, although associations of TMT switch with other EF measures were weak. All SES indices other than parental education level significantly associated with multiple EF measures. CFT and reading speed had slightly stronger correlations with SES than did most of the EF measures. The pattern and strength of associations were similar cross-sectionally and longitudinally, with fewer significant associations longitudinally, likely in part explained by the drop in n at T2.

3.3. Regression models

Multiple regressions with full information maximum likelihood estimation, a method that takes into account all available data, were used to predict performance on EF measures cross-sectionally at T1 from the SES indices and control variables, and longitudinally at T2, controlling for T1 EF, thereby testing for SES effects on developmental change over the T1-T2 period. $n = 2726$ for all models presented in the main text (see **Supplementary Materials Fig. S8** for the models rerun in the full cohort of state school SCAMP pupils).

3.3.1. General associations

SES explained 1 % of additional variance in the T1 EF factor after accounting for demographic controls and the T1 SES factor had a small but significant positive association with the T1 EF factor (β = 0.11, 95 % CI [0.07, 0.15], $p < .001$). Longitudinally, the SES factor again explained an additional 1 % of variance after controls and had a small but significant association with change in the EF factor from T1 to T2 (β = 0.07, 95 % CI [0.04, 0.11], $p < .001$) (see **Supplemental Materials Table S5** for the full model parameter estimates). These associations translate into an effect the size of a 2 IQ point increase per SD increase in SES cross-sectionally and a 1 IQ point increase longitudinally.

For comparison, the same models were run with non-verbal reasoning and language scores as outcomes to explore the extent to which they were associated with SES compared to EF. The SES factor explained 3 % of the variance in T1 non-verbal reasoning (β = 0.18, 95 % CI [0.14, 0.22], $p < .001$) after relevant controls and 2 % in age 11 reading (β = 0.16, 95 % CI [0.12, 0.20], $p < .001$). Longitudinally, 1 % of additional variance in T2 non-verbal reasoning was explained (β = 0.11, 95 % CI [0.07, 0.14], $p < .001$). Fig. 1a shows that cross-sectional and longitudinal associations between the SES factor and non-verbal reasoning/reading were larger than the associations between the SES factor and EF.

3.3.2. Differential relations between SES indices and EF

The percentage of variance in EF composite score explained by SES was unchanged when we treated the SES indices as individual predictors rather than a factor. Cross-sectionally, all SES indices other than area level deprivation significantly predicted unique variance in T1 EF. However, only parental occupation and FSM status were significantly associated with the *change* in EF over adolescence in longitudinal models, showing these factors were associated with increasing gaps between children's EF skills (Fig. 1b, Table 6).

3.3.3. Sensitivity of different EF measures to SES

Cross-sectionally at age 12, there was limited specificity in the relationships between the SES factor and different EF measures; all EF measures other than TMT switch cost were significantly associated with SES (Table 7 and Fig. 1c), with SES explaining up to 1 % of additional variance after accounting for demographic characteristics. This remained true after false discovery rate (FDR) correction across the six comparisons. However, longitudinally SES was only related to change in performance on the WM tasks (Table 7, Fig. 1c). After controlling for demographic characteristics, an additional 1 % of the change in BDS and Corsi span over adolescence was explained by the SES factor (see Table 7 for the full models R^2 values). The SES-WM span associations remained significant after FDR correction but not the association of SES with SWM errors.

Table 3
Average scores on the executive function tasks and comparison measures at T1 and T2.

	n T1	T1 *M (SD)*	*n* T2	T2 *M (SD)*	*n* T1 & T2	% change T1-T2[a]	T1-T2 *r*[b]
TMT switch cost	2636	1.83 (0.58)	2573	1.79 (0.56)	2493	−2.7 %***	0.22***
BDS score	2503	4.02 (0.86)	2604	4.33 (0.96)	2416	7.5 %***	0.50***
SWM errors	2616	29.19 (13.15)	2425	26.35 (12.66)	2339	−10.11 %***	0.34***
SWM strategy	2619	10.71 (2.82)	2431	10.34 (2.89)	2345	−3.5 %***	0.18***
Corsi span	1584	4.93 (0.75)	979	5.20 (0.89)	747	6.1 %***	0.49***
CPT errors	586	5.07 (5.10)	351	4.22 (5.04)	159	−28.80 %***	0.34***
CFT score	2451	13.16 (3.63)	2489	14.23 (3.63)	2254	8.9 %***	0.49***
Reading SAT score	2558	4.41 (0.75)	N/A				

Notes. TMT = Trail Making Task; BDS = Backwards Digit Span; SWM = Spatial Working Memory; CPT = Continuous Performance Task; CFT = Culture Fair Test; SAT = Standardised Assessment Test. For CFT, BDS, Corsi, and SAT, a higher score = better performance. For TMT switch cost, SWM errors, SWM strategy, CPT errors, a higher score = worse performance.

[a] Paired t-tests were carried out to compare T1 and T2 performance for participants with longitudinal data.

[b] Pearson correlations were carried out between T1 and T2 data. Tasks were completed in a fixed order so, due to time constraints and differences between participants, the number of participants differs for each task.

*** $p < .001$.

Table 4
Cross-sectional correlation matrix for the demographic, socioeconomic status, and cognitive measures at T1 (Age 12 Years).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. T1 Gender															
2. T1 Age	0.00														
3. Parent education	-0.08***	-0.04	*SES – SES associations*												
4. T1 Parent occupation	-0.04*	0.02	0.34***												
5. T1 Area deprivation	0.11***	0.00	-0.17***	-0.23***											
6. T1 Free School Meals	-0.02	0.02	-0.14***	-0.13***	0.18***										
7. T1 SES factor	-0.08***	-0.01	0.72***	0.83***	-0.56***	-0.42***									
8. T1 CFT score	0.03	0.08***	0.12***	0.11***	-0.11***	-0.10***	0.16***								
9. Reading SAT†	0.04*	0.05*	0.09***	0.17***	-0.08***	-0.11***	0.16***	0.32***							
10. T1 TMT switch	-0.01	0.02	-0.04	0.00	0.03	0.02	-0.02	-0.07***	0.05*	*T1 EF – EF associations*					
11. T1 BDS span	0.07***	0.03	0.06*	0.06**	-0.02	-0.05**	0.07***	0.36***	.031***	-0.08***					
12. T1 SWM errors	-0.07***	-0.03	-0.02	-0.05*	0.07***	0.05*	-0.07***	-0.26***	-0.23***	0.07***	-0.26***				
13. T1 SWM strategy	0.01	0.01	-0.02	-0.04	0.03	0.02	-0.04	-0.15***	-0.10***	0.04	-0.12***	0.55***			
14. T1 Corsi span	0.02	0.05*	0.02	0.05	-0.01	-0.06*	0.05	0.28***	0.22***	-0.11***	0.32***	-0.27***	-0.20***		
15. T1 CPT errors	-0.01	-0.04	-0.05	-0.11**	0.10*	0.00	-0.11**	-0.14***	-0.13***	0.09*	-0.16***	0.16***	0.13**	-0.21***	
16. T1 EF factor	0.07***	0.04*	0.05*	0.08***	-0.06**	-0.07***	0.09***	0.40***	0.32***	-0.22***	0.77***	-0.67***	-0.37***	0.79***	-0.50***

Notes. SES = socioeconomic status; CFT = Cattel's Culture Fair Test; SAT = Standardised Assessment Test; TMT = Trail Making Task; BDS = Backwards Digit Span; SWM = Spatial Working Memory; CPT = Continuous Performance Task; EF = executive function. For EF, CFT, BDS, Corsi, and SAT a higher score = better performance. For TMT switch cost, SWM errors, SWM strategy and CPT errors, a higher score = worse performance. Gender is coded as female = 1. †This measure was collected in the year prior to T1. * $p < .05$, ** $p < .01$, *** $p < .001$. Darker blue shades indicate stronger positive correlations, darker red shades indicate stronger negative correlations.

Table 5
Correlation matrix for associations between T1 demographic and socioeconomic status measures and T2 cognitive measures (Age 14 Years).

	1. T1 Gender	2. T1 Age	3. Parent education	4. T1 Parent occupation	5. T1 Area deprivation	6. T1 Free School Meals	**7. T1 SES factor**	8	9	10	11	12	13	14	15
8. T1-T2 Lag time	-0.05**	-0.27***	-0.07**	-0.06**	0.21***	0.12***	-0.15***								
9. T2 CFT score	0.05**	0.09***	0.10***	0.14***	-0.10**	-0.12***	0.17***	-0.01							
10. T2 TMT switch	0	-0.02	0.01	0	0.06**	0.01	-0.02	0.02	-0.06**	*T2 EF – EF associations*					
11. T2 BDS span	0.08***	0.03	0.06**	0.08***	-0.02	-0.08***	0.09***	0.06**	0.38***	-0.10***					
12. T2 SWM errors	-0.09***	-0.02	0	-0.05*	0.05*	0.06**	-0.06**	-0.01	-0.28***	0.05*	-0.32***				
13. T2 SWM strategy	0.03	-0.05*	-0.01	-0.03	0	0.02	-0.03	-0.01	-0.17***	0.02	-0.19***	0.58***			
14. T2 Corsi span	0.06	0.06	0	0.10**	-0.04	-0.04	0.07*	0.05	0.31***	-0.13***	0.34***	-0.34***	-0.19***		
15. T2 CPT errors	-0.07	0.08	-0.05	-0.09	-0.03	-0.06	-0.04	-0.06	-0.30***	0.07	-0.30***	0.19***	0.14*	-0.25***	
16. T2 EF factor	0.10***	0.04*	0.04	0.10***	-0.05**	-0.08***	0.10***	0.05*	0.42***	-0.20***	0.82***	-0.75***	-0.43***	0.76***	-0.61***

Notes. SES = SES; CFT = Cattel's Culture Fair Test.; TMT = Trail Making Task; BDS = Backwards Digit Span; SWM = Spatial Working Memory; CPT = Continuous Performance Task; EF = executive function. For EF, CFT, BDS, and Corsi, a higher score = better performance. For TMT switch cost, SWM errors, SWM strategy and CPT errors, a higher score = worse performance. Gender is coded as female = 1. †This measure was collected in the year prior to T1. * $p < .05$, ** $p < .01$, *** $p < .001$. Darker blue shades indicate stronger positive correlations, darker red shades indicate stronger negative correlations.

We further tested for specificity of associations by looking at individual SES indices as predictors of performance on individual EF measures both cross-sectionally and longitudinally (**Supplemental Material Fig. S9**). These were low-powered tests, no associations were significant after FDR correction for 24 comparisons (four SES indices x six EF measures) cross-sectionally or longitudinally. However, they reveal a pattern of results that complement the first set of analyses. Firstly, parent occupation and FSM status were the most reliable SES predictors. Note rerunning models with non-verbal reasoning and reading as outcomes showed the same pattern of results (**Supplemental Materials Table S6**). Secondly, the BDS and Corsi task measures were particularly sensitive to these aspects of SES. Additional specific associations were observed, notably with area deprivation, but these should be interpreted with caution.

3.3.4. *Does school quality explain SES-EF associations during adolescence?*

As a final step, we reran our main analyses including Office for Standards in Education, Children's Services and Skills (Ofsted) ratings of school quality as an additional predictor to rule out the possibly that supposed family level SES effects were driven by schooling effects. All results were robust to the inclusion of this predictor with standardised βs for significant associations changing by no more than 0.01. See **Supplementary Materials** for an explanation of this measure and **Tables S7-S8** for the results from these analyses.

4. Discussion

This study explored the nature and specificity of associations between SES and EF in a large longitudinal dataset with measures from early to mid-adolescence.

In line with previous research in childhood and adolescence, SES was associated with EF cross-sectionally at age 12. In addition, our results provide the first demonstrations that the association between SES and EF skills from early to mid-adolescence and EF skills increases from early to mid-adolescence (12 to 14 years). These relations are correlational in nature and small (equivalent in size to 2 IQ points per SD difference in SES cross-sectionally and 1 point longitudinally) but they are noteworthy as they indicate a *widening* EF gap over an average of only two

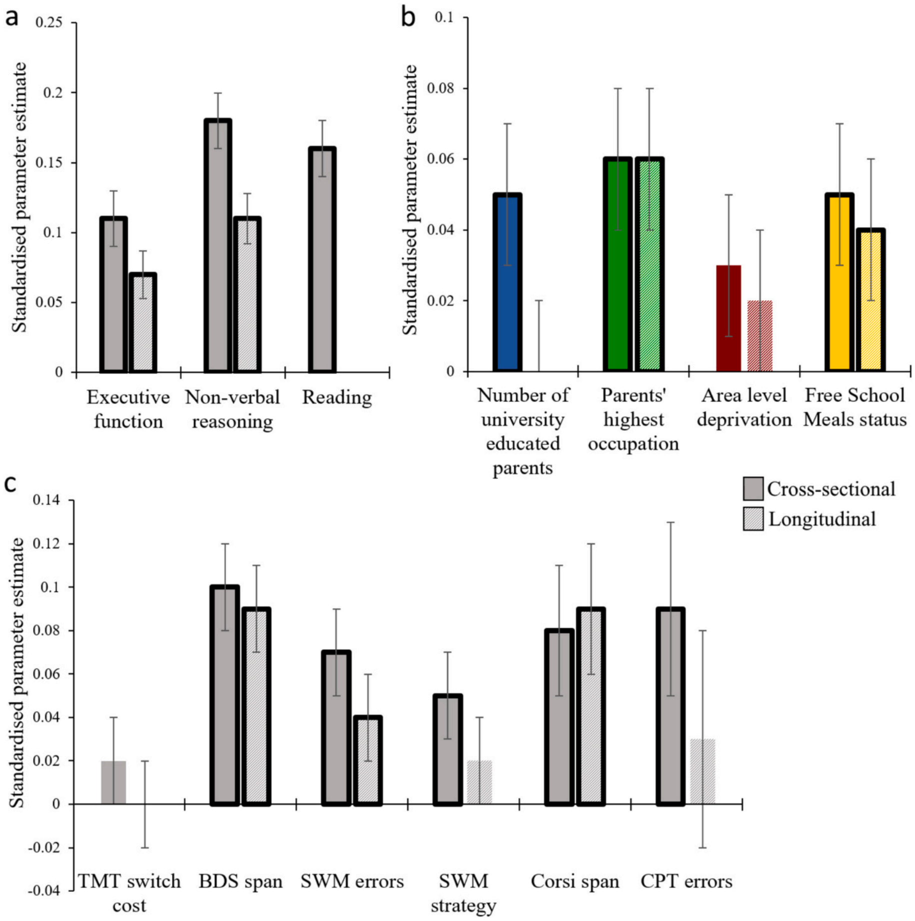

Fig. 1. Bar Graphs Showing Standardised Beta Estimates for the Cross-sectional (T1, filled bars) and Longitudinal (T2, controlling for T1, hashed bars) Associations between Cognitive Measures and socioeconomic status (SES) indices. (a) T1 SES Factor as Predictor of the executive function (EF) factor, Non-verbal Reasoning Score, and Age 11 Reading Score. (b) Individual SES Indices as Predictors of T1 (Cross-sectional) and T2 (Longitudinal) EF Factors. (c) T1 SES Factor as Predictor of Individual EF Measures.

Note. Bold outlines indicate significant associations ($p < .05$). Cross-sectional analyses are carried out at age 12 years old, longitudinal analyses between 12 and 14 years old.

Negative signs are omitted from this figure to facilitate comparison of the relative strengths of associations. For the direction of these associations, please see section 3.3.1 and Tables 6-7.

years with the measurement lag time being as small as 8 months for some adolescents. This time frame is much shorter than in many previous longitudinal studies, hence the effect sizes we observed were unsurprisingly smaller (see Lawson et al., 2018). Research spanning the whole of adolescence is needed to test whether the pattern of an increasing socioeconomic gradient in EF persists beyond age 14 and to further our understanding of possible windows of opportunity for intervention.

It should also be noted that the figures presented in this paper are relatively small as they are highly conservative estimates which reflect potential SES contributions to individual differences in EF having accounted for ethnicity and first language status – factors that correlate with SES and which are likely to share some overlapping mechanisms of impact on cognitive development (e.g., see Banerjee, 2016). The effect sizes reported here are in line with research that simultaneously modelled the effects of multiple SES indicators on age 5 cognitive outcomes, controlling for demographic factors (Schoon et al., 2021).

At age 12, all SES indices except area deprivation were uniquely

Table 6
Parameter estimates for each socioeconomic status index entered in the multiple regressions predicting the EF factor at T1 (Cross-sectional Model) and T2 Controlling for T1 (Longitudinal Model).

Predictor	Cross-sectional		Longitudinal	
	β [95 % CIs]	B [95 % CIs]	β [95 % CIs]	B [95 % CIs]
Number of university educated parents	**0.05 [0.00, 0.10]** *	0.04 [0.00, 0.08]	0.00 [−0.04, 0.04]	0.00 [−0.03, 0.04]
Parents' highest occupation	**0.06 [0.02, 0.11]** **	0.02 [0.01, 0.04]	**0.06 [0.02, 0.10]** **	0.02 [0.01, 0.04]
Area level deprivation	−0.03 [−0.07, 0.01]	−0.02 [−0.04, 0.01]	−0.02 [−0.06, 0.01]	−0.01 [−0.03, 0.01]
Free School Meals status	**−0.05 [−0.09, −0.01]** *	−0.09 [−0.16, −0.02]	**−0.04 [−0.07, −0.01]** *	−0.07 [−0.13, −0.01]
Full model R^2	0.05		0.33	

Note.
Significant betas are highlighted in bold.
* $p < .05$.
** $p < .01$.

Table 7
Parameter estimates for T1 Socioeconomic status factor associations with different executive function measures at T1 (Cross-sectional Models) or T2 controlling for T1 (Longitudinal Models) and variance explained by the whole models.

	Cross-sectional models			Longitudinal models		
	SES β [95 % CIs]	SES B [95 % CIs]	R^2	SES β [95 % CIs]	SES B [95 % CIs]	R^2
TMT switch	−0.02 [−0.05, 0.03]	−0.01 [−0.05, 0.02]	0.01	0.00 [−0.04, 0.04]	0.00 [−0.04, 0.03]	0.06
BDS span	**0.10 [0.06, 0.14]** ***	**0.12 [0.07, 0.17]**	0.03	**0.09 [0.05, 0.12]** ***	**0.12 [0.07, 0.16]**	0.28
SWM errors	**−0.07 [−0.11, −0.03]** ***	**−1.35 [−2.08, −0.62]**	0.03	−0.04 [−0.08, 0.00]*	−0.74 [−1.45, −0.04]	0.13
SWM strategy	**−0.05 [−0.09, −0.01]** *	**−0.18 [−0.34, −0.02]**	0.01	−0.02 [−0.25, 0.09]	−0.08 [−0.25, 0.09]	0.04
Corsi span	**0.08 [0.03, 0.15]** **	**0.08 [0.03, 0.13]**	0.04	**0.09 [0.03, 0.15]** **	**0.11 [0.04, 0.19]**	0.26
CPT errors	**−0.09 [−0.17, −0.01]** *	**−0.64 [−1.25, −0.04]**	0.02	−0.03 [−0.13, 0.08]	−0.20 [−0.94, 0.54]	0.20

Notes. Beta values describe the effect of a 1 SD increase in the socioeconomic status (SES) factor on different executive function (EF) measures. TMT = Trail Making Task; BDS = Backwards Digit Span; SWM = Spatial Working Memory; CPT = Continuous Performance Task; EF = EF; SES = socioeconomic status. Significant betas after FDR correction (*p*-value thresholds corrected for six comparisons cross-sectionally and six longitudinally) are in bold. Cross-sectional analyses are carried out at age 12 years old, longitudinal analyses between 12 and 14 years old.

associated with EF. We replicated Madhushanthi et al. (2020)'s finding of a cross-sectional association between parental education and WM during adolescence, as well as Donati et al.'s (2019) finding that parental occupation correlates with EF in UK adolescents (Table 1). However, we found that parental occupation and a marker of low income were cross-sectionally associated with EF, unlike Madhushanthi et al. (2020). Area deprivation associations with EF, reported by Sutin et al. (2022), may have been observed if more up-to-date population statistics were available or our data were less skewed since SES effects are stronger in more socioeconomically diverse samples (Lawson et al., 2018). Further research into the importance of this predictor in adolescence is needed.

Longitudinally, FSM and parental occupation were significant associated with change in EF. These findings extend Donati et al.'s (2019) results and suggest that parental occupation related inequalities in EF increase through adolescence Supplementary analyses ruled out the possibility that these supposed family level effects were in fact driven by differences in school quality. These findings lend support Bukodi and Goldthorpe's (2013) assertion that sociocultural and economic resources have separable effects on child development. However, since cognitive skills were measured only twice, we are unable to tell whether our findings reflect stable individual differences or rank order changes. Further research mapping the developmental trajectories of EF for students from different socioeconomic backgrounds from childhood through adolescence is needed to discern between these possibilities and the contribution of this study should be understood as primarily descriptive and correlational.

A plausible explanation for our finding that income poverty predicts associates with change in EF during adolescence is that there are social inequalities in access to extracurricular activities thought to benefit EF in the UK– e.g., private tutoring, playing musical instruments and sports participation (Diamond & Lee, 2011; Zhang, 2018) – and parents' occupation prestige may influence the extent to which they encourage participation in such activities. Parents working unsociable hours (common in low prestige jobs in the UK; Lyonette & Clark, 2009) may also be less able to supervise their children and prevent them from engaging in risky health behaviours which negatively influence cognitive development (e.g., drinking alcohol). FSM associations may also be explained by nutrition (e.g., Verstynen et al., 2012) and reflect family composition; because of the low threshold for eligibility, pupils in receipt of FSM are often from single parent families, something that none of our other measures were sensitive to. Previous research has shown that, amongst children from low SES families, children from single parent families score lower on EF measures than those from two parent families (Sarsour et al., 2011). The associations of Free School Meals status with cognitive and academic outcomes reported here might therefore index the interaction between income and being raised in a single parent family.

Unlike income and occupation, in this study, area deprivation was not significantly related to EF cross-sectionally or longitudinally. This finding is inconsistent with Sutin et al. (2022) who identified a longitudinal association of this index with cognitive skills in Australian adolescents. The rapid redevelopment of historically poorer London neighbourhoods due to gentrification may have meant that our index based on 2011 census records may not be a valid account of relative deprivation in this study. It is possible that the pattern of area-level deprivation – EF associations observed here might have been different if more up to date population statistics were available or had the area deprivation data been less skewed. This study offers the only evidence, to our knowledge, of the relationship between area deprivation and change in EF over adolescence, so further research into the importance of this predictor is needed.

Several studies have shown significant longitudinal relations between parental education level and EF during childhood (e.g., Tucker-Drob, 2013; Davis-Kean et al., 2021). It is therefore possible that the cross-sectional association we observed at T1 reflects the prior effects of factors related to parent education on EF during childhood. The changing nature of parent-child and child-peer relationships that occurs during adolescence, which could mean that the mechanisms through which different SES indices influence cognitive development change, may go some way to explain this difference between the cross-sectional and longitudinal analyses. Longitudinal research is needed across the transitional period from primary to secondary education to explore this possibility. It has also been suggested that parental education effects on cognitive development might operate through their influence on household income (i.e., highly educated parents have higher earning potential; Noble et al., 2015). Further, we note that parental education levels may have been more varied in the countries in which the previous studies were conducted in, making comparisons difficult to draw.

The SES factor showed fairly non-discriminate associations with EF measures at age 12 but specific associations with WM span tasks longitudinally. These differential effects of SES on specific aspects of EF are consistent with previous studies of adolescents (Madhushanthi et al., 2020; Sutin et al., 2022) and adults (Mittal et al., 2015) and with the predictions of cognitive adaptation theory (e.g., Mittal et al., 2015). However, they are inconsistent with findings from child samples (Lawson et al., 2018), suggesting that differential relationships between SES and different EF measures may not be observable/emerge until adolescence. Age related differences could be because of lower reliability of individual EF measures for children (Lawson et al., 2018), increasing differentiation of EF over adolescence (Karr et al., 2018; Lee et al., 2013) or compounding effects of SES over time (e.g., Hackman et al., 2015). The longitudinal relationships between SES and our WM span tasks were slightly larger than the longitudinal relations between SES and the EF factor. The extended developmental trajectory of WM skills and the systems which subserve them through adolescence (e.g., Finn et al., 2010) may make them relatively more vulnerable to the compounding effects of SES over time than other EFs.

By contrast, some evidence suggests that shifting may be a relative strength of individuals from disadvantaged backgrounds (Mittal et al., 2015). It has been suggested that it may be adaptive to quickly switch between task goals in the context of a chaotic and unpredictable home environment. Consistent with the idea that switching is a well-practiced skill in individuals from low SES families, Mittal et al. (2015) found that adults who grew up in stressful home environments were faster on a switching task without any accuracy trade-offs. This may be why we observed a SES gradient in switching neither cross-sectionally nor longitudinally. However, our switching measure also showed a relatively low T1-T2 correlation, suggesting low reliability. Switching has rarely been studied in this context, so these results need replicating.

4.1. Implications

These findings are consistent with Furhmann et al.'s (2015) notion of early adolescence as a sensitive period for cognitive development. However, we offer preliminary evidence suggesting that not all skills are equally sensitive to environmental influence during this period. Following Furmann et al., the potential sensitivity of working memory to environmental factors in this period may mean that there is increased opportunity for interventions to reduce inequalities between students.

Given the well-established link between EF skills and attainment (Ding et al., 2024), the findings from this study suggest that students living in poverty and students whose parents have low occupation prestige may benefit from activities that help strengthen EF, particularly working memory. However, we urge that interventions specifically focusing on working memory in low SES adolescents are likely to do little to level up social inequalities in attainment unless they are very intensive. In this cohort, we observed small associations between SES and changes in working memory skills over an average of a two-year period and most working memory training interventions are light touch and last only for a maximum of several months (e.g., Melby-Lervåg & Hulme, 2013). Further, social inequalities in attainment are likely best explained by multiple cognitive, social and emotional factors (Banerjee, 2016) so focusing on working memory alone is likely to have only modest effects.

4.2. Strengths and limitations

In this study, we were able to explore longitudinal SES – EF associations in a large cohort, controlling for sociodemographic factors, allowing us to detect nuanced relationships and small, but possibly consequential increases in EF inequalities through adolescence. We have interpreted these as reflection potential SES effects which unfold specifically during adolescence. However, since family SES tends to remain relatively stable during childhood and adolescence (Hackman et al., 2015), it is possible that they reflect the impact of experiences earlier in childhood that laid the foundation for different rates of EF development through adolescence. In addition, since cognitive skills were measured only twice, we are unable to tell whether our findings reflect stable individual differences or rank order changes. Further research mapping the developmental trajectories of EF for students from different socioeconomic backgrounds from childhood through adolescence is needed to discern between these possibilities.

A limitation of this study is that we had multiple WM measures but only one measure of other EFs. This meant that we were not able to isolate EFs from task specific variance. Hence, some of the associations between SES and performance on specific tasks we identified may be picking up on associations of SES with other cognitive skills employed when completing those tasks. Relatively few participants completed our inhibition measure (6 % at both timepoints), reducing our power to reliably assess associations between IC and SES. Future studies should replicate our models using a greater range of EF measures and a randomised order of task presentation to ensure similar *n* for each task. While the original tasks adapted for this cohort study show adequate to excellent psychometric properties (e.g., see Bailey et al., 2018; Bombin et al., 2013; Cattell et al., 1960; Cooper & Stewart, 2017; Karlsen et al., 2022), some tasks were adapted to reduce testing time and facilitate a self-paced online testing assessment, which may have reduced their reliability.

A final limitation of this study is that we cannot rule out genetic effects that covary with SES (e.g., see Allegrini et al., 2020), since we did not employ a genetically sensitive design. EF skills are heritable, with working memory showing particularly high heritability estimates (e.g., 30 % in Donati, Meaburn, & Dumontheil, 2019), and thus some of the SES-WM associations we describe may partially index genetic effects. However, the percentage of the association between parental income and child cognitive skills attributable to genetic factors is small (e.g., 20 % in Rowe et al., 1998 compared to 63 % for the parental education – child cognitive skill link). Therefore, our longitudinal findings are unlikely to be predominantly driven by genetic effects.

4.3. Conclusion

In conclusion, this study provides the first evidence, to our knowledge, that SES gradients in EF show small increases during adolescence. At age 12, SES associations were mostly non-specific. However, longitudinal analyses showed that individual differences in EF skills associated with parental occupation and household poverty, but not parental education and area-level deprivation, increased during adolescence. We also showed that SES specifically associated with change in performance on WM span tasks from early to mid-adolescence. Future work should identify proximal sources of the associations of parental occupation and household poverty with developing EF skills to inform theory and levelling up educational interventions. Given the well-established link between individual differences in EF and educational outcomes reported elsewhere and the increase in SES-related inequalities in EF through adolescence reported here, the teenage years should be a higher research priority.

CRediT authorship contribution statement

R.C. Perry: Writing – review & editing, Writing – original draft, Visualization, Software, Formal analysis, Data curation, Conceptualization. **E. Booth:** Writing – review & editing, Investigation, Data curation. **M.S.C. Thomas:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition. **A. Tolmie:** Writing – review & editing, Supervision, Funding acquisition. **M. Röösli:** Writing – review & editing, Project administration, Funding acquisition. **M.B. Toledano:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **C. Shen:** Writing – review & editing, Resources. **I. Dumontheil:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Data curation, Conceptualization.

Accordance with human subjects guidelines

For data collection in schools, informed consent was first obtained from head teachers and eligible families were provided with information about the study. Students from the SCAMP schools were enrolled into the study if their parents consented to their participation. Parents also consented to data linkage at the stage of first enrolling in the study.

Ethics approval statement

The original SCAMP study protocol and subsequent amendments were approved by The North West-Haydock Research Ethics Committee. Ethical approval for the linkage of SCAMP data with National Pupil Database data for the purposes of RCP's PhD project was granted by the Imperial College London Research Ethics Committee (Protocol number 14IC2067, version 4, 29/07/2014). A data sharing agreement was drawn up between Birkbeck College and Imperial College, granting RCP permission to securely store and analyse a pseudonymised extract of SCAMP data.

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Declaration of competing interest

The authors have no conflicts of interest to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lindif.2025.102822.

Data availability

SCAMP data are not publicly available. However, some data can be shared on request subject to approval by the SCAMP Data Access Committee. Data access requests should be directed to Dr. Mireille B Toledano (Principal Investigator; m.toledano@imperial.ac.uk). The code for the analyses described in this paper will be made available on OSF.

References

Adjutant General's Office. (1944). Army individual test battery [database record]. *APA PsycTests.*. https://doi.org/10.1037/t31500-000

Ahmed, S. F., Ellis, A., Ward, K. P., Chaku, N., & Davis-Kean, P. E. (2022). Working memory development from early childhood to adolescence using two nationally representative samples. *Developmental Psychology, 58*(10), 1962–1973. https://doi.org/10.1037/dev0001396

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology, 111*(3), 446. https://doi.org/10.1037/edu0000296

Allegrini, A. G., Karhunen, V., Coleman, J. R. I., Selzam, S., Rimfeld, K., Stumm, S., … Plomin. (2020). Multivariable G-E interplay in the prediction of educational achievement. *PLoS Genetics, 16*(11), Article e1009153. https://doi.org/10.1371/journal.pgen.1009153

Amir, D., Jordan, M. R., & Rand, D. G. (2018). An uncertainty management perspective on long-run impacts of adversity: The influence of childhood socioeconomic status on risk, time, and social preferences. *Journal of Experimental Social Psychology, 79*, 217–226. https://doi.org/10.1016/j.jesp.2018.07.014

Bailey, R., Barnes, S. P., Park, C., Sokolovic, N., & Jones, S. M. (2018). *Executive function mapping project measures compendium: A resource for selecting measures related to executive function and other regulation-related skills in early childhood.* OPRE Report No. 2018-59.

Banerjee, P. A. (2016). A systematic review of factors linked to poor academic performance of disadvantaged students in science and maths in schools. *Cogent Education, 3*(1), Article 1178441. https://doi.org/10.1080/2331186X.2016.1178441

Bignardi, G., Mareva, S., & Astle, D. E. (2024). Parental socioeconomic status weakly predicts specific cognitive and academic skills beyond general cognitive ability. *Developmental Science, 27*(2), Article e13451. https://doi.org/10.1111/desc.13451

Bombin, I., Mayoral, M., Castro-Fornieles, J., Gonzalez-Pinto, A., De la Serna, E., Rapado-Castro, M., et al. (2013). Neuropsychological evidence for abnormal neurodevelopment associated with early-onset psychoses. *Psychological Medicine, 43*, 757–768. https://doi.org/10.1017/S0033291712001535

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26*(2), 571–593. https://doi.org/10.1207/s15326942dn2602_3

Bukodi, E., & Goldthorpe, J. H. (2013). Decomposing 'social origins': The effects of parents' class, status, and education on the educational attainment of their children. *European Sociological Review, 29*(5), 1024–1039. https://doi.org/10.1093/esr/jcs079

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. https://www.jstor.org/stable/canajeducrevucan.32.3.558.

Carstairs, V., & Morris, R. (1990). Deprivation and health in Scotland. *Health Bulletin, 48*(4), 162–175.

Cattell, R. B., Cattell, A. K. S., & Institute for Personality and Ability Testing. (1960). *Measuring intelligence with the culture fair tests.* Institute for Personality and Ability Testing.

Choudhury, S., Piera Pi-Sunyer, B., & Blakemore, S. J. (2023). A neuroecosocial perspective on adolescent development. *Annual Review of Developmental Psychology, 5*(1), 285–307. https://doi.org/10.1146/annurev-devpsych-120321-011511

Cooper, K., & Stewart, K. (2017). *Does money affect children's outcomes? An update (CASEpaper 203)*. Centre for Analysis of Social Exclusion. https://sticerd.lse.ac.uk/dps/case/cp/casepaper203.pdf.

Davis-Kean, P. E., & Sexton, H. R. (2009). Race differences in parental influences on child achievement: Multiple pathways to success. *Merrill-Palmer Quarterly, 55*(3), 285–318. https://www.jstor.org/stable/23096259.

Davis-Kean, P. E., Tighe, L. A., & Waters, N. E. (2021). The role of parent educational attainment in parenting and children's development. *Current Directions in Psychological Science, 30*(2), 186–192. https://doi.org/10.1177/0963721421993116

Destin, M., Richman, S., Varner, F., & Mandara, J. (2012). "Feeling" hierarchy: The pathway from subjective social status to achievement. *Journal of Adolescence, 35*(6), 1571–1579. https://doi.org/10.1016/j.adolescence.2012.06.006

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Ding, X., Li, S., Zhang, X., & Shi, J. (2024). The mediating role of executive function between socioeconomic status and academic achievement: A meta-analytic structural equation model. *Learning and Individual Differences, 110*, Article 102418. https://doi.org/10.1016/j.lindif.2024.102418

Donati, G., Dumontheil, I., & Meaburn, E. L. (2019). Genome-wide association study of latent cognitive measures in adolescence: Genetic overlap with intelligence and education. *Mind, Brain, and Education, 13*(3), 224–233. https://doi.org/10.1111/mbe.12198

Donati, G., Meaburn, E. L., & Dumontheil, I. (2019). The specificity of associations between cognition and attainment in English, maths and science during adolescence. *Learning and Individual Differences, 69*, 84–93. https://www.sciencedirect.com/science/article/pii/S1041608018301882.

Dumontheil, I., & Klingberg, T. (2012). Brain activity during a visuospatial working memory task predicts arithmetical performance 2 years later. *Cerebral Cortex, 22*(5), 1078–1085. https://doi.org/10.1093/cercor/bhr175

Engel de Abreu, P. M. J., Cruz-Santos, A., Tourinho, C. J., Martin, R., & Bialystok, E. (2012). Bilingualism enriches the poor: Enhanced cognitive control in low-income minority children. *Psychological Science, 23*(11), 1364–1371. https://doi.org/10.1177/0956797612443836

Farah, M. J. (2017). The neuroscience of socioeconomic status: Correlates, causes, and consequences. *Neuron, 96*(1), 56–71. https://doi.org/10.1016/j.neuron.2017.08.034

Field, A. (2009). *Discovering statistics using SPSS.* SAGE Publications.

Filippi, R., Ceccolini, A., Booth, E., Shen, C., Thomas, M. S. C., Toledano, M. B., & Dumontheil, I. (2022). Modulatory effects of SES and multilinguistic experience on cognitive development: A longitudinal data analysis of multilingual and monolingual adolescents from the SCAMP cohort. *International Journal of Bilingual Education and Bilingualism, 0*(0), 1–18. https://doi.org/10.1080/13670050.2022.2064191

Finn, A. S., Sheridan, M. A., Kam, C. L. H., Hinshaw, S., & D'Esposito, M. (2010). Longitudinal evidence for functional specialization of the neural circuit supporting working memory in the human brain. *Journal of Neuroscience, 30*(33), 11062–11067. https://doi.org/10.1523/JNEUROSCI.6266-09.2010

Frankenhuis, W. E., & Nettle, D. (2020). The strengths of people in poverty. *Current Directions in Psychological Science, 29*(1), 16–21. https://doi.org/10.1177/0963721419881154

Fuhrmann, D., Knoll, L. J., & Blakemore, S. J. (2015). Adolescence as a sensitive period of brain development. *Trends in Cognitive Sciences, 19*(10), 558–566.

Galioto, R., Britton, K., Bond, D. S., Gunstad, J., Pera, V., Rathier, L., & Tremont, G. (2018). Executive functions are associated with weight loss during participation in a medically supervised weight loss program. *Obesity Medicine, 9*, 18–20. https://doi.org/10.1016/j.obmed.2017.12.002

GOV.UK. (2016). Schools, pupils and their characteristics: January 2016. https://www.gov.uk/government/statistics/schools-pupils-and-their-characteristics-january-2016.

GOV.UK. (2018). Socioeconomic status. https://www.ethnicity-facts-figures.service.gov.uk/uk-population-by-ethnicity/demographics/socioeconomic-status/latest.

Grissom, N., M., & Reyes, T. M. (2019). Let's call the whole thing off: Evaluating gender and sex differences in executive function. *Neuropsychopharmacology, 44*, 86–96. https://doi.org/10.1038/s41386-018-0179-5

Guo, G. (1998). The timing of the influences of cumulative poverty on children's cognitive ability and achievement. *Social Forces, 77*(1), 257–288. https://doi.org/10.1093/sf/77.1.257

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: Developmental trajectories and mediation. *Developmental Science, 18*(5), 686–702. https://doi.org/10.1111/desc.12246

Herting, M. M., Younan, D., Campbell, C. E., & Chen, J.-C. (2019). Outdoor air pollution and brain structure and function from across childhood to young adulthood: A methodological review of brain MRI studies. *Frontiers in Public Health, 7*. https://www.frontiersin.org/articles/10.3389/fpubh.2019.00332.

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia, 44*(11), 2017–2036. https://doi.org/10.1016/j.neuropsychologia.2006.01.010

Icenogle, G., & Cauffman, E. (2021). Adolescent decision making: A decade in review. *Journal of Research on Adolescence, 31*(4), 1006–1022. https://doi.org/10.1111/jora.12608

Johnson, A., Bathelt, J., Akarca, D., Crickmore, G., & Astle, D. E. (2021). Far and wide: Associations between childhood socio-economic status and brain connectomics. *Developmental Cognitive Neuroscience, 48*, Article 100888. https://doi.org/10.1016/j.dcn.2020.100888

Karlsen, R. H., Karr, J. E., Saksvik, S. B., Lundervold, A. J., Hjemdal, O., Olsen, A., & Skandsen, T. (2022). Examining 3-month test-retest reliability and reliable change using the Cambridge neuropsychological test automated battery. *Applied Neuropsychology. Adult, 29*(2), 146–154. https://doi.org/10.1080/23279095.2020.1722126

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. *Psychological Bulletin, 144*(11), 1147–1185. https://doi.org/10.1037/bul0000160

Lawson, G. M., Hook, C. J., & Farah, M. J. (2018). A meta-analysis of the relationship between socioeconomic status and executive function performance among children. *Developmental Science, 21*(2), Article e12529. https://doi.org/10.1111/desc.12529

Lee, K., Bull, R., & Ho, R. M. H. (2013). Developmental changes in executive functioning. *Child Development, 84*(6), 1933–1953. https://doi.org/10.1111/cdev.12096

Letkiewicz, A. M., Miller, G. A., Crocker, L. D., Warren, S. L., Infantolino, Z. P., Mimnaugh, K. J., & Heller, W. (2014). Executive function deficits in daily life prospectively predict increases in depressive symptoms. *Cognitive Therapy and Research, 38*(6), 612–620. https://doi.org/10.1007/s10608-014-9629-5

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *Journal of the Acoustical Society of America, 49*, 467–477. https://doi.org/10.1121/1.1912375

Long, J. S., & Freese, J. (2006). *Regression models for categorical dependent variables using Stata, Second Edition*. Stata Press.

Luciana, M., & Nelson, C. A. (2002). Assessment of neuropsychological function through use of the Cambridge Neuropsychological Testing Automated Battery: Performance in 4- to 12-year-old children. *Developmental Neuropsychology, 22*(3), 595–624. https://doi.org/10.1207/S15326942DN2203_3

Lyonette, C., & Clark, M. (2009). *Unsocial hours: Unsocial families? Working Time and Family Wellbeing*. Relationships Foundation.

Madhushanthi, H. J., Wimalasekera, S. W., Goonewardena, C. S. E., Amarasekara, A. A. T. D., & Lenora, J. (2020). Socioeconomic status is a predictor of neurocognitive performance of early female adolescents. *International Journal of Adolescent Medicine and Health, 32*(6). https://doi.org/10.1515/ijamh-2018-0024

McNeish, D. (2023). A practical guide to selecting and blending approaches for clustered data: Clustered errors, multilevel models, and fixed-effect models. *Psychological Methods*. https://doi.org/10.1037/met0000620

McNeish, D., & Kelley, K. (2019). Fixed effects models versus mixed effects models for clustered data: Reviewing the approaches, disentangling the differences, and making recommendations. *Psychological Methods, 24*(1), 20–35. https://doi.org/10.1037/met0000182

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? *A meta-analytic review. Developmental Psychology, 49*(2), 270.

Mittal, C., Griskevicius, V., Simpson, J. A., Sung, S., & Young, E. S. (2015). Cognitive adaptations to stressful environments: When childhood adversity enhances adult executive function. *Journal of Personality and Social Psychology, 109*, 604–621. https://doi.org/10.1037/pspi0000028

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Morris, S., Farran, E. K., & Dumontheil, I. (2019). Field independence associates with mathematics and science performance in 5- to 10-year-olds after accounting for domain-general factors. *Mind, Brain, and Education, 13*(4), 268–278. https://doi.org/10.1111/mbe.12214

Moya, M., & Fiske, S. T. (2017). The social psychology of the great recession and social class divides. *Journal of Social Issues, 73*(1), 8–22. https://doi.org/10.1111/josi.12201

Murtha, K., Larsen, B., Pines, A., Parkes, L., Moore, T. M., Adebimpe, A., … Satterthwaite, T. D. (2022). Associations between neighborhood socioeconomic status, parental education, and executive system activation in youth. *Cerebral Cortex*. , Article bhac120. https://doi.org/10.1093/cercor/bhac120

Noble, K. G., Houston, S. M., Brito, N. H., Bartsch, H., Kan, E., Kuperman, J. M., … Sowell, E. R. (2015). Family income, parental education and brain structure in children and adolescents. *Nature Neuroscience, 18*(5). https://doi.org/10.1038/nn.3983. Article 5.

Office for National Statistics. (2010). *The National Statistics Socio-economic classification (NS-SEC rebased on SOC2010). 3*. Office for National Statistics. SOC2010 https://www.ons.gov.uk/methodology/classificationsandstandards/standardoccupationalclassificationsoc/soc2010/soc2010volume3thenationalstatisticssocioeconomicclassificationnssecrebasedonsoc2010#category-descriptions-and-operational-issues.

Office for National Statistics. (2022). Industry and occupation, England and Wales. https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/bulletins/industryandoccupationenglandandwales/census2021.

Pasta, D. (2009). Learning when to be discrete: Continuous vs. *Categorical Predictors. SAS Global Forum, 2009*. https://support.sas.com/resources/papers/proceedings09/248-2009.pdf.

Piccolo, L.d. R., Arteche, A. X., Fonseca, R. P., Grassi-Oliveira, R., & Salles, J. F. (2016). Influence of family socioeconomic status on IQ, language, memory and executive functions of Brazilian children. *Psicologia: Reflexão e Crítica, 29*. https://doi.org/10.1186/s41155-016-0016-x

Pluck, G., Córdova, M. A., Bock, C., Chalen, I., & Trueba, A. F. (2021). Socio-economic status, executive functions, and theory of mind ability in adolescents: Relationships with language ability and cortisol. *British Journal of Developmental Psychology, 39*(1), 19–38. https://doi.org/10.1111/bjdp.12354

Rakesh, D., Seguin, C., Zalesky, A., Cropley, V., & Whittle, S. (2021). Associations between neighborhood disadvantage, resting-state functional connectivity, and behavior in the adolescent brain cognitive development study: The moderating role of positive family and school environments. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 6*(9), 877–886. https://doi.org/10.1016/j.bpsc.2021.03.008

Rea-Sandin, G., Korous, K. M., & Causadias, J. M. (2021). A systematic review and meta-analysis of racial/ethnic differences and similarities in executive function performance in the United States. *Neuropsychology, 35*(2), 141–156. https://doi.org/10.1037/neu0000715

Rosen, M. L., Amso, D., & McLaughlin, K. A. (2019). The role of the visual association cortex in scaffolding prefrontal cortex development: A novel mechanism linking socioeconomic status and executive function. *Developmental Cognitive Neuroscience, 39*, Article 100699. https://doi.org/10.1016/j.dcn.2019.100699

Ross, C. E., & Mirowsky, J. (2008). Neighborhood socioeconomic status and health: Context or composition? *City & Community, 7*(2), 163–179. https://doi.org/10.1111/j.1540-6040.2008.00251.x

Rowe, D. C., Vesterdal, W. J., & Rodgers, J. L. (1998). Herrnstein's syllogism: Genetic and shared environmental influences on IQ, education, and income. *Intelligence, 26*(4), 405–423. https://doi.org/10.1016/S0160-2896(99)00008-2

Sarsour, K., Sheridan, M., Jutte, D., Nuru-Jeter, A., Hinshaw, S., & Boyce, W. T. (2011). Family socioeconomic status and child executive functions: The roles of language, home environment, and single parenthood. *Journal of the International Neuropsychological Society, 17*(1), 120–132. https://doi.org/10.1017/S1355617710001335

Schoon, I., Nasim, B., & Cook, R. (2021). Social inequalities in early childhood competences, and the relative role of social and emotional versus cognitive skills in predicting adult outcomes. *British Educational Research Journal, 47*(5), 1259–1280. https://doi.org/10.1002/berj.3724

Shucksmith, M., Glass, J., Chapman, P., & Atterton, J. (2023). *Rural poverty today: Experiences of social exclusion in rural Britain*. Policy Press. https://bristoluniversitypress.co.uk/rural-poverty-today.

Simmonds, D. J., Hallquist, M. N., & Luna, B. (2017). Protracted development of executive and mnemonic brain systems underlying working memory in adolescence: A longitudinal fMRI study. *NeuroImage, 157*, 695–704. https://doi.org/10.1016/j.neuroimage.2017.01.016

Sutin, A. R., Sesker, A. A., Stephan, Y., & Terracciano, A. (2022). Socioeconomic status, internalizing and externalizing behaviors, and executive function in adolescence: A longitudinal study with multiple informants. *Psychiatry Research, 313*, Article 114585. https://doi.org/10.1016/j.psychres.2022.114585

Thomas, M. S. C., & Coecke, S. (2023). Associations between socioeconomic status, cognition, and brain structure: Evaluating potential causal pathways through mechanistic models of development. *Cognitive Science, 47*(1), Article e13217. https://doi.org/10.1111/cogs.13217

Toledano, M., .B., Mutz, J., Röösli, M., Thomas, M., S, C., Dumontheil, I., & Elliott, P. (2018). Cohort profile: The study of cognition, adolescents and mobile phones (SCAMP). *International Journal of Epidemiology, 48*(1), 25–26l. https://doi.org/10.1093/ije/dyy192

Tucker-Drob, E. M. (2013). How many pathways underlie socioeconomic differences in the development of cognition and achievement? *Learning and Individual Differences, 25*, 12–20. https://doi.org/10.1016/j.lindif.2013.01.015

Verstynen, T. D., Weinstein, A. M., Schneider, W. W., Jakicic, J. M., Rofey, D. L., & Erickson, K. I. (2012). Increased body mass index is associated with a global and distributed decrease in white matter microstructural integrity. *Psychosomatic Medicine, 74*(7), 682. https://doi.org/10.1097/PSY.0b013e318261909c

Zhang, Y. (2018). Private tutoring, students' cognitive ability and school engagement, and the formal schooling context: Evidence from middle school students in China. *Chinese Journal of Sociology, 4*(2), 277–298. https://doi.org/10.1177/2057150X18764859