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The associations between intergenerational mobility of income and cognitive function in midlife–The Young Finns Study

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ABSTRACT

Background: Systematically high and upward mobile (lower childhood and higher adulthood) socioeconomic status (SES) has been suggested to be associated with better overall cognitive function in adulthood compared to systematically low or downward mobile (high childhood and low adulthood) SES.
Methods: Participants' SES mobility was assessed using data on childhood family income (N = 3596, age 3–18) and own adulthood income (N = 1941, age 34–49). Adulthood learning and memory, working memory, information processing, and reaction time were measured using a computerized test. Altogether, 1804 participants had data on life-course income level and cognitive function in adulthood.
Results: Compared to participants with stable high income, those with stable low, downward, or upward mobile income had worse memory and learning, and information processing. Participants with stable low or downward mobile income had worse working memory and reaction time. The results persisted after adjusting for age, sex, childhood/adulthood lifestyle, cardiovascular risk factors, and polygenic risk score for cognitive function.
Conclusions: Individuals with stable high income may have better midlife cognitive function. This finding highlights the role of life-course SES for disparities in adulthood cognitive function. Understanding the role of early-life determinants of midlife cognitive function is important, as this knowledge may be applied to the early promotion of adulthood cognitive health.

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1. Introduction

Cognitive function is essential for daily functioning and overall quality of life since it forms the foundation for our ability to think, make decisions, learn, and remember. Cognitive function has its origin in the fetal period, after which it rapidly develops in childhood and adolescence. The developmental phase continues until early adulthood, after which cognitive function starts to decline slowly until old age. Importantly, even though a slight decline in cognitive function is inevitable during aging, the slope of the decline is not such that it greatly violates activities of daily living. Furthermore, most of the dementias, e.g., Alzheimer's disease, have a long preclinical phase before the clinical diagnosis of dementia (Porsteinsson et al., 2021). There is some evidence that cognitive function measured in adulthood is associated with dementia incidence over two decades later, which highlights the importance of studying cognitively healthy middle-aged participants (Wang et al., 2023)

A recent meta-analysis showed a positive association between adulthood occupational level, education, and stimulating activities and cognitive function (Opdebeeck et al., 2016). In several studies, high adulthood socioeconomic status (SES) has been associated with better overall cognitive function (Fors et al., 2009; Jefferson et al., 2011; Vemuri et al., 2014; Wilson et al., 2009; Zhang et al., 2019) and performance on specific cognitive domains such as verbal memory (Steptoe and Zaninotto, 2020) and fluency (Steptoe and Zaninotto, 2020), and semantic memory (Jefferson et al., 2011). Prior studies have also established the association of childhood SES with cognitive function later in life (Aartsen et al., 2019; Fors et al., 2009; Greenfield and Moorman, 2019; Y. Liu and Lachman, 2019; Marden et al., 2017; Zhang et al., 2017) by demonstrating that high childhood SES predicts better overall cognitive function (Fors et al., 2009), and its components, including memory functions (e.g. verbal and episodic memory) (Aartsen et al., 2019; Greenfield and Moorman, 2019; Y. Liu and Lachman, 2019; Marden et al., 2017; Zhang et al., 2017), verbal fluency (Aartsen et al., 2019), and executive function (Greenfield and Moorman, 2019; Y. Liu and Lachman, 2019). Although in many studies the associations between childhood SES and later cognitive function were attenuated when adjusted for participants' adulthood SES, only a few studies have explicitly examined at which stages during the life course SES most strongly influences cognitive function (Greenfield and Moorman, 2019; Y. Liu and Lachman, 2019; Zhang et al., 2017). The indicators of SES vary between studies; e.g., education, income, occupational level, community-level SES, or a combination of these have been used.

Many life-course models for SES have been proposed, but the most influential have been the critical period, accumulation of risks, and the pathway models. According to the critical period model, adverse exposures in a specific time window have the most prominent effects on development, with less excess risk outside this developmental window (Khandaker et al., 2018; Kuh et al., 2003; Pearce et al., 2005). Childhood has been suggested to be a critical period by many studies that have found associations between childhood SES and adult health outcomes and noted that these are independent of adulthood social circumstances (Claussen et al., 2003; Gliksman et al., 1995; Pollitt et al., 2005). The accumulation model proposes that adverse exposures over the life-course cause cumulative damage to psychological and biological systems. The accumulation model has been supported in studies showing that greater time spent in adverse SES translates into worse health and well-being outcomes (Singh-Manoux et al., 2004). The pathway model suggests that early-life exposures influence later life experiences and opportunities, determining later adversities. One prior study proposes a developmental process linking early-life psychosocial environments with adult health risk via pathway effects. Early experiences would thus place an individual onto a certain trajectory, eventually impacting adult health outcomes (Hertzman et al., 2001).

One way of analyzing the relative importance of SES in different life stages on cognitive performance is to focus on intergenerational SES mobility. Intergenerational SES mobility refers to the ability of individuals to move up or down the socioeconomic ladder compared to their parents. For instance, stable high SES means that the individual was born into high SES and has been able to maintain it. Simultaneously, an individual who is called "upward mobile" was originally born into low SES but has moved upwards, while "downward mobile SES" refers to mobility vice versa. Stable high SES has been associated with higher global cognitive function when compared to stable low SES (Krasnova et al., 2023). One study showed that older adults who had stable high SES from childhood to adulthood or who were upwardly mobile had better general cognitive function from age 65 compared to those who had stable low SES or who were downwardly mobile (Lyu and Burr, 2016). Some studies suggest that adulthood SES has a higher impact on adulthood cognitive function than childhood SES, since the upward mobile SES seems to be more beneficial for cognitive capacity compared to the downward mobile SES (Y. Liu and Lachman, 2019; Peterson et al., 2021). There is also evidence that adulthood SES is important regarding some specific cognitive domains. Compared to the stable low SES group, high stable and upward mobile SES have been associated with better verbal memory (Peterson et al., 2021), semantic memory (Peterson et al., 2021), and executive function (Y. Liu and Lachman, 2019; Peterson et al., 2021). However, there is a lack of studies with prospectively collected data on SES from childhood to adulthood linked with data on multiple cognitive domains assessed in adulthood.

In this study, we examined whether intergenerational income mobility is associated with cognitive function in midlife using data from the ongoing longitudinal population-based Cardiovascular Risk in Young Finns Study (YFS). Over the 30 years of follow-up, data on income and education have been collected repeatedly from childhood to adulthood.

2. Methods

2.1. Participants

Young Finns Study was originally designed to study cardiovascular risk factor levels and their determinants among Finnish children and adolescents (Raitakari et al., 2008). During the baseline study in 1980, 3596 randomly selected children and adolescents (males and females; ages 3, 6, 9, 12, 15, and 18 years; 83 % of the invited) were recruited. The cohort has been followed regularly in 1983, 1986, 1989, 2001, 2007, and 2011.

2.2. Intergenerational mobility of SES

Annual income was considered as an indicator of SES in childhood (parental/family income in 1980) and adulthood (own income in 2011) (R. S. Liu et al., 2016). Parental annual income strata were determined on an 8-point and a 13-point scale: at the baseline from 1 (≤7000€, 4.8 %, transformed to correspond with the value of money at the time of cognitive testing) to 8 (>46,000€, 8.3 %) and in adulthood (follow-up study in 2011) from 1 (≤5000€, 3.3 %) to 13 (>60,000€, 9.9 %) (Elovainio et al., 2012). First, the variables were dichotomized according to the definition of the Organisation for Economic Co-operation and Development, where the poverty level is 50 % of median income (Inequality - Poverty Rate - OECD Data). Childhood income was dichotomized into low (≤21,000€; 40.7 %) and high (>21,000€; 59.3 %) SES groups. Adulthood income was divided similarly using an annual income of 30,000€ as a cutoff value. Participants with annual income <30,000€ belonged to the low income group (42.3 %). Subsequently, the study population was classified into four groups according to their income in childhood and adulthood:1) stable low income (low income in childhood and adulthood; N = 365, 20.2 %); 2) downward mobile income (high income in childhood but low income in adulthood; N = 399, 22.1 %); 3) upward mobile income (low income in childhood but high income in adulthood; N = 370, 20.5 %); and 4) stable high income (high income in childhood and adulthood; N = 670, 37.1 %).

Education was used as an alternative indicator of SES. Data on parental education years were collected in follow-up studies in 1980, 1983, and 1986, and the maximum of parents' education years was used as an indicator for the childhood family education. The maximum number of participant's education years was assessed from data collected in all adulthood follow-up studies. The variables were dichotomized using the median as a cutoff (median and higher considered as high education). The median for parental education was 10 years, and for participants' education was 15 years. After dichotomizing the childhood and adulthood education data, the study population was classified into four intergenerational education mobility groups similar to income.

2.3. Cognitive function

In 2011, cognitive testing was conducted on 2026 Young Finns Study participants using a computerized cognitive testing battery (CANTAB, Cambridge Cognition, Cambridge, United Kingdom). Among all available subtests, the Young Finns Study test battery was selected so that it was feasible to accomplish in a large population-based setting, reflected different domains of cognitive function, and could be used as an indicator of overall cognitive function. The test battery included four tests measuring: 1) visual and episodic memory and visuospatial associative learning (hereafter learning and memory); 2) short-term and spatial working memory (working memory); 3) visual information processing, recognition, and sustained attention (information processing); and 4) reaction and movement time (reaction time). Principal component analysis was conducted to identify domain-specific components accounting for the majority of the variation within the dataset (Rovio et al., 2016). The components were normalized using a rank order normalization procedure, resulting in variables, each with a mean of 0 and a standard deviation (SD) of 1. Standardized outcome variables were used in order to set the outcome variables all on the same scale to enable comparison of the effect sizes between the cognitive domain outcomes and between the different SES indicators (income and education). Detailed descriptions of the cognitive testing and the principal component analysis are presented in the Supplemental material. Validation of the Young Finns Study cognitive data has been published previously (Rovio et al., 2016).

2.4. Covariates

Age was defined as full years at the cognitive testing. Smoking, alcohol drinking, and physical activity were considered as lifestyle-related covariates. Smoking was queried at the baseline and in all follow-up studies from participants aged 12 years and older, and the participants were dichotomized into daily smokers and non-smokers. Participants aged under 12 years were considered non-smokers. Similarly, alcohol use was queried from the participants aged 12 years and older. Participants reporting any drinking of alcohol at the baseline were considered alcohol users, while those reporting never drinking and those who were aged under 12 years were considered non-drinkers. Adulthood alcohol drinking was assessed as self-reported alcohol units per day. Physical activity was queried at baseline and in all follow-up studies. As in previous studies, a physical activity index was calculated by combining information on frequency and intensity of physical activity, hours spent on vigorous physical activity, average duration of a physical activity session, and participation in organized physical activity (Telama et al., 2005).

To overcome the lack of baseline cognitive function data, a polygenic score (N = 1759) was calculated based on a GWAS on intelligence (Savage et al., 2018) to indicate genetic propensity for cognitive function (Browning and Browning, 2008; Savage et al., 2018; Teo et al., 2007; Vilhjálmsson et al., 2015). Polygenic risk score summarizes the information on each specific single-nucleotide polymorphism (SNP), applying also their effect sizes in relation to cognitive function. Thus, it may be used as an indicator of overall genetic propensity of cognitive function. Supplemental analyses were also conducted using data on school performance as an alternative proxy for childhood cognitive function. Self-reported information on childhood school performance (N = 1777) expressed as grade point average (*i.e.* average of grades in all individual school subjects at baseline for those who were of school age or either of the two subsequent follow-ups for those participants who were not of school age at baseline) was collected and the average was used as a proxy for childhood cognitive function.

Results from the Young Finns Study data have previously shown that cardiovascular risk factors from childhood may have associations with cognitive function in midlife that are independent of the corresponding adulthood exposures (Rovio et al., 2017). Similarly, higher childhood socioeconomic status has been linked with lower risk of metabolic syndrome (Puolakka et al., 2016) and lower arterial stiffness (Puolakka et al., 2017a,b) in adulthood. Simultaneously, we have observed that low childhood SES is associated with smoking and lower physical activity in adulthood (Puolakka et al., 2017). Therefore, we conducted supplemental analyses adjusting for cardiovascular risk factors, including systolic blood pressure, serum total cholesterol, and body mass index (BMI) from childhood/adolescence and adulthood. Standard methods were used for measuring systolic blood pressure and serum total cholesterol. In all phases, the participants' weight and height were measured and their BMI calculated (kg/m^2).

2.5. Statistical analyses

The associations of intergenerational income mobility with cognitive function in midlife were studied using linear regression. The regression models were constructed under the assumption that all missing data was missing at random. Thus, we conducted the regression models adjusting for those variables that might have affected missingness (i.e. those that differed between the participants and non-participants). Age at cognitive testing and sex were used as covariates in all analyses (Model 1). Model 2 was adjusted additionally for childhood/adolescence lifestyle factors (smoking, alcohol drinking, and physical activity), and Model 3 for corresponding adulthood factors. Subsequently, all models were conducted adjusting additionally for the polygenic risk score for cognitive function. To put the results into clinical perspective, we transformed the found associations between intergenerational mobility of income and the studied cognitive domains to correspond with 'cognitive aging'; *i.e.*, we compared the β estimates of the income mobility groups to the β estimates of age in the cognitive test-specific age, sex and genetic propensity for cognitive function adjusted models (Table 4). Finally, we also tested the possible effect modification of genetic propensity for cognitive function for the association between intergenerational mobility of income and cognitive function by adding a multiplicative interaction term into the age and sex-adjusted models for each cognitive domain.

Supplemental analyses were conducted first using education as an indicator of SES. Secondly, the cardiovascular covariates from childhood/adolescence and adulthood were entered into the model separately (Model 2B for childhood/adolescence and Model 3B for adulthood risk factors). Third, supplemental analyses were also conducted, replacing the polygenic risk score for cognitive function with childhood school performance as a proxy for childhood cognitive function. The stable high income or education group was used as the reference group in the analyses. Additionally, analyses were conducted using the upward income group as the reference group to test the critical period life-course model. All statistical analyses were conducted using SAS 9.4. The level of statistical significance was $p < 0.05$.

3. Results

3.1. Characteristics of the study population

The characteristics of the study population and the number of participants in each cognitive domain are presented in Table 1. At the time of cognitive testing, the mean age of the participants was 41.8 years, and 45.3 % of them were men. In 1980, 59.3 % of the participants had an annual family income over 21,000€, while in 2011, 57.7 % of the participants had an annual income over 30,000€. The participants with cognitive function data were older, more often females, had higher BMI, and were more often alcohol users at baseline compared to those who had no data on cognitive function. The participants with cognitive data also had better school performance and were less likely to have family income below 21,000€ in childhood (Supplemental Table 1). The cognitive domain-specific age and sex-adjusted mean values for each intergenerational income group are shown in Fig. 1. Supplemental Fig. 1 presents the Young Finns Study participation. Noticeably, over half of those participants who lost to follow-up at some point in the study have taken part in at least some of the later follow-ups.

Table 1
Characteristics of the study population.

	N	
Age, years (mean, SD)		
At baseline	1804	10.8 (5.0)
At cognitive testing	1804	41.8 (5.0)
Male sex, %	1804	45.3
Total years of education at cognitive testing (mean, SD)	1788	15.4 (3.6)
Daily smoking, %		
At baseline	1780	26.5
At cognitive testing	1798	14.4
Body mass index, kg/m^2 (mean, SD)		
At baseline	1791	17.9 (3.1)
At cognitive testing	1799	26.5 (5.1)
Physical activity (mean, SD)		
At baseline	1759	
3-6 y	534	16.2 (2.3)
9-18 y	1225	9.0 (1.8)
At cognitive testing	1726	9.1 (1.9)
Alcohol use		
At baseline, %	1804	28.1
At cognitive testing (mean, SD)	1772	0.8 (1.2)
Income, %	1804	
At baseline/Family income over 21,000€	1069	59.3
At cognitive testing/Own income over 30,000€	1040	57.7
Income mobility, %	1804	
Stable low	365	20.2
Downward mobile	399	22.1
Upward mobile	370	20.5
Stable high	670	37.1
Cognitive function		
Memory and learning (PAL-test)	1636	*Cognitive function variables were standardized; mean = 0, SD = 1*
Working memory (SWM-test)	1791	
Information processing (RVP-test)	1760	
Reaction time (RTI-test)	1613	

Values are means (standard deviations) for continuous variables and percentages for categorical variables. Smoking habits were queried at the baseline and in all follow-up studies from participants aged 12 years and older. Childhood physical activity index at baseline ranged between 9 and 22 among those aged 3–6 years and between 5 and 14 among those aged 9–18 years. Participants reporting any drinking of alcohol at the baseline were considered alcohol users while those reporting never drinking and those who were aged under 12 years were considered non-drinkers. Adulthood alcohol drinking was assessed as self-reported alcohol units per day.

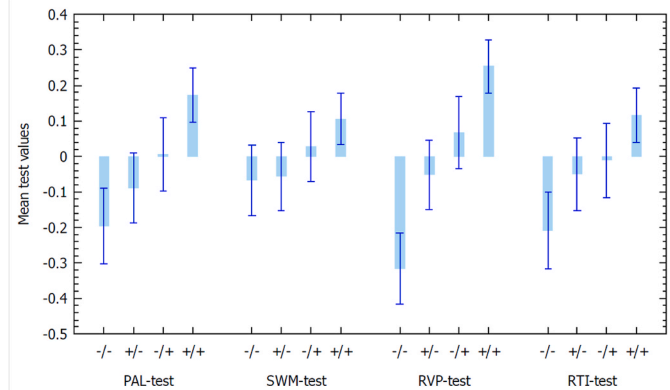

Fig. 1. Age and sex adjusted mean cognitive function domains (SD-scale) in the childhood/adulthood income groups. Blue bars indicate the mean values adjusted for age and sex for each cognitive test. Deep blue lines represent the 95 % confidence intervals. Groups: -/- = participants with stable low income; +/- = participants with downward income mobility; −/+ = participants with upward income mobility; +/+ = participants with stable high income. PAL=Paired Associates Learning test; SWM=Spatial Working Memory test; RTI=Reaction Time test; RVP= Rapid Visual Information Processing test. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2. Intergenerational mobility of SES and cognitive function in midlife

Compared to the stable high income group, all cognitive domains were lower in the stable low income group when adjusted for age and sex (learning and memory: $\beta = -0.339$, SE = 0.07, $p < 0.001$; working memory: $\beta = -0.146$, SE = 0.07, $p = 0.025$; information processing: $\beta = -0.533$, SE = 0.07, $p < 0.001$; reaction time: $\beta = -0.281$, SE = 0.07, $p < 0.001$; Table 2, Model 1). The observed associations remained similar after additional adjustments for childhood/adolescence or adulthood smoking, alcohol use, and physical activity (Table 2, Model 2, and Model 3).

Similarly, when compared to the stable high income group, the downward mobile income was found to associate inversely with all cognitive domains in the age and sex-adjusted analyses (learning and memory: $\beta = -0.247$, SE = 0.07, $p < 0.001$; working memory: $\beta = -0.157$, SE = 0.06, $p = 0.014$; information processing: $\beta = -0.296$, SE = 0.06, $p < 0.001$; reaction time: $\beta = -0.155$, SE = 0.07, $p = 0.021$; Table 2, Model 1). The results remained virtually identical after additional adjustments for childhood/adolescence smoking, alcohol use, and physical activity (Model 2). When corresponding adulthood lifestyle risk factors were taken into account, the associations remained unchanged for all other cognitive domains except for reaction time, for which the association was diluted (Model 3).

Compared to the stable high income, the age and sex-adjusted analyses revealed an inverse association for the upward mobile SES with memory and learning ($\beta = -0.143$, SE = 0.07, $p = 0.030$, Model 1) and information processing ($\beta = -0.197$, SE = 0.07, $p = 0.003$, Model 1). These associations remained virtually unchanged after additional adjustments for childhood and adulthood lifestyle factors (Model 2 and Model 3). No associations were found for the upward mobile income group with other cognitive domains.

When the upward income group was used as the reference group, an inverse association was observed for the stable low income with memory and learning ($\beta = -0.196$, SE = 0.08, $p = 0.012$; Table 3, Model 1), information processing ($\beta = -0.336$, SE = 0.08, $p < 0.001$, Model 1) and reaction time ($\beta = -0.159$, SE = 0.08, $p = 0.046$, Model 1). Although the difference between downward and upward income groups was not statistically significant, the general pattern of downward income group having lower mean values compared to the upward income group can be observed in Fig. 1.

Table 2
The associations between intergenerational mobility of income and cognitive function in midlife, using the stable high income group as the reference.

	Model 1		Model 2		Model 3	
	β (SE)	p-value	β (SE)	p-value	β (SE)	p-value
Memory and learning (*PAL-test*; n = 1568)						
−/−	−0.339 (0.07)	**<0.001**	−0.336 (0.07)	**<0.001**	−0.332 (0.07)	**<0.001**
+/−	−0.247 (0.07)	**<0.001**	−0.245 (0.07)	**<0.001**	−0.241 (0.07)	**<0.001**
−/+	−0.143 (0.07)	**0.030**	−0.140 (0.07)	**0.034**	−0.142 (0.07)	**0.033**
Working memory (*SWM-test*; n = 1715)						
−/−	−0.146 (0.07)	**0.025**	−0.140 (0.07)	**0.032**	−0.140 (0.07)	**0.034**
+/−	−0.157 (0.06)	**0.014**	−0.151 (0.06)	**0.018**	−0.149 (0.06)	**0.020**
−/+	−0.060 (0.06)	0.343	−0.059 (0.07)	0.356	−0.048 (0.06)	0.450
Information processing (*RVP-test*; n = 1685)						
−/−	−0.533 (0.07)	**<0.001**	−0.520 (0.07)	**<0.001**	−0.507 (0.07)	**<0.001**
+/−	−0.296 (0.06)	**<0.001**	−0.285 (0.06)	**<0.001**	−0.268 (0.07)	**0.004**
−/+	−0.197 (0.07)	**0.003**	−0.194 (0.06)	**0.003**	−0.168 (0.07)	**0.010**
Reaction time (*RTI-test;* n = 1545)						
−/−	−0.281 (0.07)	**<0.001**	−0.277 (0.07)	**<0.001**	−0.240 (0.07)	**<0.001**
+/−	−0.155 (0.07)	**0.021**	−0.157 (0.07)	**0.019**	−0.116 (0.07)	0.085
−/+	−0.122 (0.07)	0.071	−0.111 (0.07)	0.099	−0.096 (0.07)	0.152

Numbers are β coefficients (standard errors) and p-values from linear models. In all analyses, the stable high income group was used as the reference category. Model 1 is adjusted for age and sex. Model 2 is adjusted for age, sex, and childhood/adolescence smoking, alcohol use, and physical activity. Model 3 is adjusted for age, sex, and adulthood smoking, alcohol use, and physical activity. Paired Associates Learning (PAL) test measures episodic memory and associative learning; Spatial Working Memory (SWM) test measures working memory and executive function; Rapid Visual Information (RVP) test measures visual information processing and sustained attention; Reaction Time (RTI) test measures reaction and movement time. In all analyses, the participants with stable high income (+/+) are used as the reference category. −/− = participants with stable low income; +/− = participants with downward income mobility; −/+ = participants with upward income mobility

Table 3
The associations between intergenerational mobility of income and cognitive function in midlife, using the upward income group as the reference.

	Model 1		Model 2		Model 3	
	β (SE)	p-value	β (SE)	p-value	β (SE)	p-value
Memory and learning (*PAL-test*) (n = 1636)						
−/−	−0.196 (0.08)	**0.012**	−0.196 (0.08)	**0.012**	−0.191 (0.08)	**0.015**
+/−	−0.103 (0.08)	0.171	−0.105 (0.08)	0.167	−0.099 (0.08)	0.189
+/+	0.143 (0.07)	**0.030**	0.140 (0.07)	**0.034**	0.142 (0.07)	**0.033**
Working memory (*SWM-test*) (n = 1715)						
−/−	−0.085 (0.07)	0.247	−0.081 (0.07)	0.272	−0.091 (0.07)	0.217
+/−	−0.096 (0.07)	0.185	−0.093 (0.07)	0.203	−0.101 (0.07)	0.166
+/+	0.060 (0.06)	0.343	0.059 (0.06)	0.356	0.048 (0.06)	0.450
Information processing (*RVP-test*) (n = 1685)						
−/−	−0.336 (0.08)	**<0.001**	−0.326 (0.08)	**<0.001**	−0.339 (0.08)	**<0.001**
+/−	−0.099 (0.07)	0.185	−0.091 (0.07)	0.220	−0.100 (0.07)	0.179
+/+	0.197 (0.07)	**0.003**	0.194 (0.06)	**0.003**	0.168 (0.07)	**0.010**
Reaction time (*RTI-test*) (n = 1545)						
−/−	−0.159 (0.08)	**0.046**	−0.166 (0.08)	**0.037**	−0.143 (0.08)	0.072
+/−	−0.033 (0.08)	0.670	−0.046 (0.08)	0.545	−0.020 (0.08)	0.799
+/+	0.122 (0.07)	0.071	0.111 (0.07)	0.099	0.096 (0.07)	0.152

Numbers are β coefficients (standard errors) and p-values from linear models. Model 1 is adjusted for age and sex. In all analyses, the upward income group was used as the reference category. Model 2 is adjusted for age, sex, and childhood/adolescence smoking, alcohol use, and physical activity. Model 3 is adjusted for age, sex, and adulthood smoking, alcohol use, and physical activity. Paired Associates Learning (PAL) test measures episodic memory and associative learning; Spatial Working Memory (SWM) test measures working memory and executive function; Rapid Visual Information (RVP) test measures visual information processing and sustained attention; Reaction Time (RTI) test measures reaction and movement time. In the analyses, the participants with upward income (−/+) are used as the reference category. −/− = participants with stable low income; +/− = participants with downward income mobility; +/+ = participants with stable high income.

To account for the genetic propensity for cognitive function, we conducted all analyses adjusting additionally for the polygenic risk score for cognitive function (Table 4). In general, the point estimates were somewhat reduced in these analyses but remained significant for the stable low and downward mobile income groups, pointing systematically to the associations between these groups and poor cognitive function in each of the cognitive domains. No effect modification of genetic propensity for cognitive function was observed for the found associations (data not shown).

To put the results into clinical perspective, we transformed the found statistically significant associations between intergenerational mobility of income and the studied cognitive domains to correspond with ‘cognitive aging’; (estimates for age: PAL-test $\beta = -0.053$, SE = 0.005; SWM-test $\beta = -0.045$, SE = 0.005; RVP-test $\beta = -0.023$, SE = 0.005; RTI-test $\beta = -0.016$, SE = 0.005) (Fig. 2). For example, for memory and learning, the point estimate for the stable low income group corresponded to the effect of 5.0 years of aging, while for information processing, the effect estimate of the stable low income group corresponded to 20.2 years of aging.

Supplemental analyses were conducted by first replacing income with education as the indicator of SES. In general, the associations were similar to those observed in the main analyses applying income as the indicator of SES. However, compared to those participants who had stable high education, those who had experienced upward mobile education performed better in terms of working memory ($\beta = 0.142$, SE = 0.06, $p = 0.028$, Supplemental Table 2, Model 3). Additionally, different from the main analyses, we observed no association between downward mobile education and working memory when compared to the stable high education group. Second, we conducted the analyses with upward income as a reference group, adjusting additionally for genetic

Table 4
The associations between intergenerational mobility of income and cognitive function in midlife adjusted for genetic propensity for cognitive function.

	Model 1		Model 2		Model 3	
	β (SE)	p-value	β (SE)	p-value	β (SE)	p-value
Memory and learning (*PAL-test*; n = 1373)						
−/−	−0.263 (0.07)	**<0.001**	−0.257 (0.07)	**<0.001**	−0.263 (0.07)	**<0.001**
+/−	−0.207 (0.07)	**0.003**	−0.202 (0.07)	**0.004**	−0.207 (0.07)	**0.004**
−/+	−0.124 (0.07)	0.077	−0.121 (0.07)	0.086	−0.123 (0.07)	0.080
Working memory (*SWM-test*; n = 1501)						
−/−	−0.145 (0.07)	**0.037**	−0.134 (0.07)	0.055	−0.139 (0.07)	**0.049**
+/−	−0.154 (0.07)	**0.023**	−0.145 (0.07)	**0.032**	−0.147 (0.07)	**0.031**
−/+	−0.042 (0.07)	0.533	−0.039 (0.07)	0.571	−0.031 (0.07)	0.651
Information processing (*RVP-test;* n = 1474)						
−/−	−0.464 (0.07)	**<0.001**	−0.446 (0.07)	**<0.001**	−0.444 (0.07)	**<0.001**
+/−	−0.189 (0.07)	**0.006**	−0.174 (0.07)	**0.011**	−0.168 (0.07)	**0.014**
−/+	−0.193 (0.07)	**0.005**	−0.189 (0.07)	**0.006**	−0.166 (0.07)	**0.015**
Reaction time (*RTI-test;* n = 1351)						
−/−	−0.251 (0.08)	**0.001**	−0.244 (0.08)	**0.001**	−0.212 (0.08)	**0.006**
+/−	−0.152 (0.07)	**0.036**	−0.156 (0.07)	**0.031**	−0.117 (0.07)	0.106
−/+	−0.097 (0.07)	0.183	−0.087 (0.07)	0.231	−0.073 (0.07)	0.312

Numbers are β coefficients (standard errors) and p-values from linear models. In all analyses, the stable high SES group was used as the reference category. Model 1 is adjusted for age, sex, and polygenic score for cognitive function. Model 2 is adjusted for age, sex, polygenic score for cognitive function, and childhood/adolescence smoking, alcohol use, and physical activity. Model 3 is adjusted for age, sex, polygenic score for cognitive function and adulthood smoking, alcohol use, and physical activity. Paired Associates Learning (PAL) test measures episodic memory and associative learning; Spatial Working Memory (SWM) test measures working memory and executive function; Rapid Visual Information (RVP) test measures visual information processing and sustained attention; Reaction Time (RTI) test measures reaction and movement time. In all analyses, the participants with stable high income (+/+) are used as the reference category. −/− = participants with stable low income; +/− = participants with downward income mobility; −/+ = participants with upward income mobility.

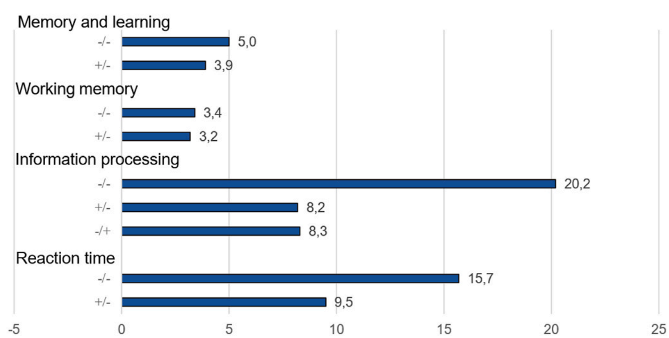

Fig. 2. Cognitive aging (years) scaled differences in cognitive function in the intergenerational mobility of income groups. In the analyses the participants with stable high income (+/+) are used as the reference category. −/− = participants with stable low income; +/− = participants with downward income mobility; −/+ = participants with upward income mobility.

propensity for cognitive function (Supplemental Table 3). Due to missing information on the genetic propensity, these analyses were conducted for a restricted number of participants (N varying between 1351 and 1501), which might affect the results. The point estimates were slightly reduced, and the p-values for memory and learning, and reaction time were no longer statistically significant. However, for information processing, the difference between upward income and stable low and stable high still remained statistically significant. Third, supplemental analyses were conducted by adjusting the models for childhood/adolescence and adulthood cardiovascular risk factors (Supplemental Table 4). In these analyses, the found associations remained virtually unchanged. Finally, supplemental analyses in which childhood school performance was taken into account as a proxy for childhood cognitive function instead of the polygenic risk score were conducted (Supplemental Table 5). In these analyses, the point estimates were marginally reduced compared to those observed when the polygenic risk score was used as a proxy for childhood cognitive function. Still, the participants with stable low or downward mobile income had poorer memory and learning, as well as information processing, than the participants with stable high income. Simultaneously, the stable low income group also had worse reaction time than the stable high income group, while no associations were observed for working memory (Supplemental Table 5).

4. Discussion

This study showed that participants whose SES, both when either income or education was used separately as the indicator, was systematically low from childhood to adulthood, and those with high SES in childhood but low in adulthood fared worse in terms of cognitive function compared with those who had stable high SES from childhood to adulthood. We also observed that participants who had stable low SES from childhood to adulthood and those who had low SES either in childhood or in adulthood had worse memory and learning, and information processing in midlife, compared to participants who had not experienced low SES. Additionally, our results indicated that participants who had stable low SES from childhood to adulthood and those who had low SES in adulthood also had significantly worse working memory and reaction time than participants in the stable high SES group. Participants who had experienced upward SES mobility also tended to have better cognitive function in midlife than those who had stable low SES both in childhood and adulthood. Altogether, the findings provide evidence on the accumulation model of socioeconomic adversity.

SES and cognitive ability have long been known to correlate (Aartsen et al., 2019; Alley et al., 2007; Fors et al., 2009; Greenfield and Moorman, 2019; Y. Liu and Lachman, 2019; Lyu and Burr, 2016), but less evidence has been available on the associations between intergenerational mobility of SES and specific cognitive domains. The findings from prior studies support our conclusions that stable high SES is associated with better cognitive function in midlife (Fu and Liu, 2022; Y. Liu and Lachman, 2019; Lyu and Burr, 2016; Peterson et al., 2021). Notably, several studies have applied retrospectively collected SES data, and/or the focus has been on general cognitive function instead of specific cognitive domains. To our knowledge, this study is among the first to apply prospectively collected data on intergenerational SES mobility coupled with detailed measures of multiple cognitive domains.

There are several possible explanations for the found association. First, there is evidence that childhood SES can influence adult cognitive function by affecting a child's morbidity (reviewed in (Kachmar et al., 2019; Poulain et al., 2020; Reiss, 2013)) and brain development (Brito and Noble, 2014; Hackman et al., 2010; Rakesh and Whittle, 2021). Moreover, higher childhood SES is linked to healthier lifestyles in adolescence and adulthood, including factors such as physical activity, a healthier diet, and non-smoking (Milas et al., 2019; Puolakka et al., 2017a,b). It has been previously noted that the effects of early-life cardiovascular risk exposures are associated with adulthood cognitive function (Rovio et al., 2017; Yaffe et al., 2014). Thus, it is possible that stable high SES reflects a favorable lifestyle and better cardiovascular risk factor profile, and therefore, links with better cognitive function in later life. Interestingly, taking into account both lifestyle-related and cardiovascular risk factors did not affect the point estimates in our analysis. This might indicate that these factors are neither confounders nor mediators for the studied associations. However, even though we took these factors into account, residual confounding might still partly explain our findings.

Prior studies applying brain imaging methods have indicated that low childhood SES, specifically low household family income (Hanson et al., 2011) and low parental education (Assari, 2020; Loued-Khenissi et al., 2022), are linked with reduced hippocampal volume among children. Apart from childhood SES, adulthood high SES has been suggested to be associated with high bilateral hippocampal grey matter volume at a mean age of 59 years (Loued-Khenissi et al., 2022). Linking to this, our observation that the Young Finns Study participants who had stable high SES had significantly better memory and learning is especially interesting, since the neural networks related to memory and learning localize mainly to medial temporal lobes, specifically to the hippocampus and parahippocampal gyrus (De Rover et al., 2011). These anatomical structures are responsible for learning and memory (Davachi et al., 2003; Squire, 1992), i.e., one of the cognitive domains for which we found systematic support in the present study. The findings related to memory and learning in our young and cognitively healthy cohort are of interest also in the light of prior findings linking deficits in the PAL-test to preclinical Alzheimer's disease pathology in elderly individuals with mild cognitive impairment (Blackwell et al., 2004; Fowler et al., 2002; Swainson et al., 2001). Furthermore, we observed no associations for those participants who had upward mobile SES in terms of working memory and reaction time. This finding might reflect the fact that difficulties in encoding and recall (*i.e.*, cognitive subdomains measured by the PAL-test) typically become detectable before difficulties in other types of memory functions (*e.g.*, working memory, recognition) (Drag and Bieliauskas, 2010).

Second, another possible explanation for the associations is that higher childhood SES allows different levels of material resources and exposures for the developing child (Cohen et al., 2010). It is plausible that parents in the lower SES groups are more likely to prioritize pressing needs over intellectual stimulation or healthy nutrition (Conger et al., 2010; Evans, 2004). Children from higher SES families are more likely to have access, e.g., to cultural resources, and their participation rate in intellectually stimulating activities may be higher than that of their lower SES counterparts (Evans, 2004; Hackman et al., 2010). Thus, the benefits gained from various activities may accumulate across the life course (Beck et al., 2018). Engagement in these activities, such as reading or cultural activities, has been associated with better global cognitive function in older adults (Jefferson et al., 2011; Vemuri et al., 2014), specifically with semantic memory (Jefferson et al., 2011) and perceptual speed (Jefferson et al., 2011). Higher childhood SES is also associated with better cognitive ability at the age of 20 years, which seems to be a powerful mediator for midlife cognitive function and is also often interlinked with cultural leisure activities in adulthood (Beck et al., 2018). However, our results indicated that those participants with low childhood SES benefited from upward SES mobility. It may indicate that individuals can counteract the negative influence of a low SES of the family, possibly through their own education, and that this has a positive effect on cognitive performance. At the same time, it shows that family SES alone is not so significant, but that skills acquired later are important. This result thus suggests that it is important to offer stimulating activities and equal access to education to all children and adolescents from various SES backgrounds.

Third, another possible pathway linking childhood SES and later cognitive outcomes is stress. Low SES is associated with higher stress levels (Cundiff et al., 2022) and mental health problems (Reiss, 2013), which in turn can impact cognitive function (Hedges and Woon, 2011; Klier and Buratto, 2020; Semkovska et al., 2019). These links may persist into adulthood as memories of financial strain in childhood are reported to be inversely associated with cognitive function in later life (Szanton et al., 2010). Stress influences the hypothalamic-pituitary-adrenal (HPA) axis regulation, which has been linked to brain and neuronal structure and cognitive outcomes (Gaysina et al., 2014; McEwen et al., 2016). In fact, childhood socioeconomic conditions have been associated with HPA axis regulation (Franz et al., 2013). It has also been suggested that families with low SES have more risky family characteristics, such as harsh discipline, violence, as well as cold and less supportive relationships (Repetti et al., 2002), all of which might be detrimental to a child's cognitive development (Berthelon et al., 2020; Savopoulos et al., 2023) and therefore, influence adulthood cognitive function (Fors et al., 2009). Also, we showed in our prior study that childhood cumulative adverse psychosocial factors are associated with poorer memory and learning in midlife (Nurmi et al., 2023). This might be explained by prior observations indicating that parental nurturance in early childhood may be important to hippocampal maturation (Rao et al., 2010).

Finally, although SES is considered an environmental factor, it is also possible that genetics plays a role in SES and its association with cognitive function (Ericsson et al., 2017). It is estimated that even up to 50–70 % of adult cognitive ability is heritable (Briley and Tucker-Drob, 2013). Additionally, shared genetic factors could explain associations between education, intelligence, and childhood and adulthood SES (Plomin and Deary, 2015). Taken together, *e.g.* the child's genetic propensity for cognitive function, his/her personal or parental interests, cognitive capacity as well as familial SES and resources may together form either positive or negative feedback loop, which at the end, paves the way for the child's cognitive development by providing the facilities for intellectual stimulation that is congruent with the child's genetically influenced intellectual interests (Tucker-Drob and Harden, 2012).

We acknowledge that our study has limitations. First, cognitive function was measured only once. Second, our main indicator of SES was income, and there could be limitations due to unemployment, poor health, and other life circumstances that affect income. However, there is evidence that income is a strong indicator of SES when investigating adulthood health outcomes (Darin-Mattsson et al., 2017). Although we assessed SES using both income and education as indicators across the life course, these were applied in separate analyses. We acknowledge that combining multiple indicators into a composite SES index may better capture the complex nature of SES, as income and education may reflect different pathways influencing the cognitive outcomes. Education is often considered to reflect cognitive resources, literacy, values, and cultural capital—factors linked with social standing and long-term behavioral patterns—whereas income more directly indicates access to material resources and opportunities (Galobardes et al., 2006). Additionally, income may be sensitive to temporary life events such as unemployment spells, while education is usually more stable across adulthood and may better represent long-term SES positioning. Importantly, we did not observe substantial differences in the studied associations when either income or education was used as the indicator of SES. This supports the interpretation that, regardless of the used indicator, SES and SES mobility might indeed play a role in determining adulthood cognitive function. Future studies should consider integrating multiple SES indicators into composite scores or latent class models to capture more comprehensive SES profiles. Third, this study only focused on family SES, which represents the participant's immediate SES surroundings, while broader SES surroundings (e.g., neighborhood) might contribute. Fourth, because the rates of SES mobility depend on how the mobility is defined and how the various groups of mobility are formed, the rates of mobility in this study cannot be fully compared with the other cohorts. Additionally, dichotomizing SES may oversimplify the variable; however, this approach was necessary to analyze intergenerational SES mobility. While we have labeled the groups as "low" and "high," we do not indicate that participants in these groups are low- or high-income individuals. The cutoffs were chosen to divide the sample into approximately equal-sized groups for analytical purposes. We also considered this division appropriate, taken the special features of the Finnish society, such as a developed social security system and equal opportunities for free schooling. These features diminish the variance of SES in Finnish society. However, despite the homogeneity of our society in terms of social deprivation and educational opportunities, we can still see the associations between the SES mobility and cognitive function. We acknowledge that our data has a historic character as the reported data collection wave dates to year 2011. This may alter the interpretability of our results to the modern context, even though income/education might be hypothesized to reflect similarly to cognitive function through decades. Furthermore, the generalizability of this study is limited to white Caucasian populations. Finally, possible bias due to loss of follow-up was present. In our study, the participants without cognitive function data were more often in the low SES group in childhood and had poor childhood school performance compared to the participants who remained within the study until the cognitive testing. However, we have previously reported that baseline risk factors were similar among participants and non-participants (Nuotio et al., 2014). Taken together, the loss to follow-up may have caused more likely underestimation rather than overestimation of the true associations. Furthermore, the Young Finns Study cohort is dynamic, meaning that a large part of the participants who were lost to follow-up at some point have returned to study later on. Major strengths of this study include the longitudinal prospective design that began in childhood and continued through 31 years of follow-up, and the participants being well-phenotyped in both childhood and adulthood (Raitakari et al., 2008). Finally, the four cognitive domains were selected as outcomes to obtain a comprehensive outlook on cognitive performance.

Supporting the accumulation theory, individuals who have stable high income or education from childhood may have better midlife cognitive function compared to those with low income or education in childhood and/or adulthood. Our study thus highlights the role of life-course SES in determining later-life cognitive function. Understanding the role of early-life determinants of midlife cognition is important, as this knowledge may be applied to the early promotion of adulthood cognitive health.

CRediT authorship contribution statement

Amanda Nurmi: Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis. **Teemu Vepsäläinen:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition. **Katja Pahkala:** Writing – review & editing, Supervision, Resources, Funding acquisition, Data curation, Conceptualization. **Elina Puolakka:** Writing – review & editing, Methodology, Funding acquisition. **Laura Pulkki-Råback:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Marko Elovainio:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Markus Juonala:** Writing – review & editing, Funding acquisition, Data curation. **Nina Hutri:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Mika Kähönen:** Writing – review & editing, Funding acquisition, Data curation. **Terho Lehtimäki:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Eero Jokinen:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Tomi P. Laitinen:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Päivi Tossavainen:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Leena Taittonen:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Jorma S.A. Viikari:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Olli T. Raitakari:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Suvi P. Rovio:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethical aspects

The YFS has been approved by the local Ethics Review Board (Turku University and Turku University Hospital), reference number 88/180/2010. The study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all individual participants included in the study. Privacy rights of human subjects have been observed.

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Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2025.118325.

Data availability

Data will be made available on request.

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