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Mediators of the associations between family income during adolescence and adult long-term memory and working memory

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ABSTRACT

Low family income during childhood is associated with multiple enduring negative outcomes, including poorer cognitive functioning in adulthood. However, mechanisms linking low family income during adolescence to adulthood cognitive outcomes are relatively unclear, as mediators of income-cognition links have mostly been examined separately. To address this, we conducted a longitudinal multiple mediation analysis of associations between adolescent family income and adulthood working memory and long-term memory using a large, national dataset ($N = 6337$). The data were sociodemographically representative of the United States (48.1% male, $M_{adult\ age}$=29.01). Potential mediators were education attainment, family education attitudes, stressful life experiences, inflammation, and perceived parental warmth. We found that education attainment mediated the associations between adolescent income and adulthood working memory and long-term memory. Additionally, stressful life events mediated the association between adolescent income and adulthood long-term memory, whereas inflammation and family education attitudes mediated the association between adolescent income and adulthood working memory. These findings suggest that limited education, less positive attitudes toward education, more stress, and heightened inflammation in low-income families predict poorer cognition in adulthood, and that intervening on each of these factors may mitigate detrimental cognitive sequelae of low family income during adolescence.

1. . Introduction

Although money might not be able to buy happiness, it is hard to overstate its importance in many people's lives. For example, income can improve access to education opportunities, lead to greater perceived parental warmth, and help to reduce life stress overall (Chevalier, Harmon, O' Sullivan, & Walker, 2013; Lee, Anderson, Horowitz, & August, 2009; Marks, 2007). In contrast, poverty can create a multifaceted barrier to professional and personal success for low-income individuals. An important factor in each of these outcomes is cognitive ability (Evans & Schamberg, 2009; Orsini et al., 1986; Whitbeck et al., 1991) and lower family income during adolescence is linked to poorer cognitive functioning in adulthood (Duncan, Kalil, & Ziol-Guest, 2018). Long-term memory, or one's ability to store and recall information over an extended period of time, and working memory, the ability to hold information in mind and use it to execute cognitive tasks, are particularly related to lower family income. For example, lower adolescent family income is associated with poorer long-term memory and executive function (Hackman, Gallop, Evans, & Farah, 2015). Importantly, working memory and long-term memory play critical roles in creating or maintaining physical and mental health, professional success, and

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overall quality of life (Diamond, 2013; Gioia, Kenworthy, & Isquith, 2010). As such, it is possible that low-income-related poor working memory and long-term memory may negatively impact several aspects of life. However, the factors that link adolescent family income to cognitive functioning in adulthood are not entirely clear. This study aims to address that gap.

One potential mediating factor in explaining links between adolescent income and adulthood cognitive functioning is education. Access to higher education is limited by lower socioeconomic status (Dahill-Brown, Witte, & Wolfe, 2016), and this limitation could potentially be viewed as a major obstacle to increasing one's socioeconomic status. However, the effects of income on education begin earlier than higher education. For example, parental income is linked to the likelihood of children leaving school by age 16 (Chevalier et al., 2013). The link between family income and educational attrition, coupled with the known link between parental income and parental education (Dahill-Brown et al., 2016), suggests that parents with less income less likely to encourage their children to pursue higher education (Crosnoe, Mistry, & Elder, 2002). Less parental encouragement to pursue higher education (i.e., less positive family attitudes towards education) could in turn give students from wealthier families an advantage over their low-income peers in pursuing higher education. Further, because education itself is thought to improve working memory and long-term memory (Springer, McIntosh, Winocur, & Grady, 2005; Finn et al., 2017), less parental encouragement to pursue higher education and less education attainment may both indirectly link low adolescent income to poorer cognitive functioning in adulthood.

In addition to education, stressful life events should be considered in relation to income and cognition. Children living in low-income households are exposed to a number of stressors not experienced to the same degree by children in higher-income households, such as food anxiety, neighborhood disadvantages, and parental stress (Kim et al., 2013). Stress, in turn, impairs both working memory and long-term memory (Shields, 2020; Shields, Sazma, & Yonelinas, 2016; Shields, Ramey, Slavich, & Yonelinas, 2019; Shields, Doty, et al., 2017; Shields, Sazma, McCullough, & Yonelinas, 2017). Moreover, in support of the idea that stressful life events is a pathway through which adolescent income predicts poorer cognition in adulthood, prior work has found chronic stress to be a mediator of the relation between adolescent poverty and reduced prefrontal cortex activity—thought to support working memory—later in adulthood (Kim et al., 2013). Taken together, these findings suggest that relatively greater stressful life events may link adolescent income to poorer working memory and long-term memory in adulthood.

Biological factors also exert numerous effects on cognition and may therefore explain part of the relation between adolescent income and adulthood cognition. For example, indicators of inflammation, such as C-reactive protein (CRP), are inversely correlated with income and other markers of socioeconomic status, as well as social factors associated with poor income (Friedman & Herd, 2010; Jousilahti, 2003; Snyder-Mackler et al., 2020). Lower income is associated with greater inflammatory activity through multiple pathways, including stress, poor diet, tobacco usage, fewer positive health behaviors, and exposure to pathogens (DeVoe et al., 2007; Goddard et al., 2020; Leung, Epel, Ritchie, Crawford, & Laraia, 2014; Marks, 2007). Greater inflammatory activity, in turn, impairs cognitive functioning (Brydon, Harrison, Walker, Steptoe, & Critchley, 2008; Harrison, Doeller, Voon, Burgess, & Critchley, 2014; Shields, Moons, & Slavich, 2017), and a recent theoretical model has contended that inflammatory activity may impair executive functions—such as working memory—in particular (Shields, Moons, et al., 2017). Surprisingly, however, little work has considered inflammatory activity as a mediator of the association between adolescent income and poorer cognition in adulthood (Koster et al., 2005).

Perceived parental warmth is another factor affected by income and that may impact cognition. Low-income parents may experience unique obstacles that make it more difficult for them to provide parental support and warmth. For example, lower parental income has been related to greater levels of parental depression and parental disruption, meaning they are more likely to get divorced (Anderson, Salk, & Hyde, 2015; Lee et al., 2009). These disruptions in the quality of perceived parental warmth can be a major source of stress for children (Lee et al., 2009; Sandler, Tein, & West, 1994), potentially causing disruptions in the development of cognitive functions. Additionally, markers of parent socioeconomic status such as income and educational attainment have been found to be associated with both perceived parental warmth, affect, and overall life satisfaction in children (J. L. C. Ma, Wong, Lau, & Lai, 2012). Moreover, parental warmth has been found to predict both working memory and long-term memory ability in adulthood (Chen et al., 2020; Petrill & Deater-Deckard, 2004; Sharifian, Kraal, Zaheed, Sol, & Zahodne, 2019). To date, however, no study to our knowledge has examined whether parental warmth mediates links between childhood or adolescent family income and adulthood cognitive functioning.

2. Current research

The current study aims to examine the simultaneous statistical influence of multiple potential mediators of the links between income and working memory and long-term memory in a multiple mediation structural equation model using a nationally representative dataset of individuals in the United States followed from adolescence into adulthood. We chose to focus on adolescent family income because although much work has focused on the associations between early childhood family income and adulthood cognition (Luo & Waite, 2005; Noble, Norman, & Farah, 2005Noble, McCandliss, & Farah, 2007; Sarsour et al., 2011), few studies have examined adolescent family income and cognition later in life. Family income can vary considerably between childhood and adolescence (Deer, Shields, Alen, & Hostinar, 2021). Because adolescence is a sensitive period during which stressors and other environmental factors related to income can cause changes in neurological structure and function (Guyer, 2020; Shields, Moons, et al., 2017), we believe addressing this gap in the literature is important. The mediators we considered were educational attainment, parental attitudes toward education, life stress, inflammation, and perceived parental warmth. Although it is possible that there are other potential mediators between income and cognition, we focused on these variables in particular because of their established links to both income and cognition. We hypothesized that all of five mediating variables would explain variance in the links between adolescent income and both working memory and long-term memory. Additionally, as described above, drawing on prior work

(Shields et al., 2019; Shields, Moons, et al., 2017) we hypothesized that inflammation and stressful life events would be more strongly associated with adulthood working memory than with adulthood long-term memory.

2. Method

2.1. Participants

Participants in this study were those who participated in relevant data collection waves in the National Longitudinal Study of Adolescent to Adult Health (Harris et al., 2019)—a nationally representative study of adolescents in the U.S in grades 7–12 in the first wave of data collection who were then followed into adulthood throughout five waves of data collection. We specifically used data from Wave I (M_{age}=14.87), Wave II (M_{age}=16.54), Wave III (M_{age}=22.32), and Wave IV (M_{age}=28.91). Although we describe the relevant method details for this study, extensive documentation for Add Health is available elsewhere (Harris et al., 2019). The study included Add Health participants that had data for any of the study variables of interest ($N = 6337$; $n = 2710$ with complete data for all study variables of interest) and the included covariates (n = 1927 with complete data for all study variables of interest and all covariates).

3. Materials

3.1. Income

The independent variable for this study was household income reported by parents of participants in Wave I (M_{age}=14.87). Participants responded to the question "About how much total income, before taxes did your family receive in 1994? Include your own income, the income of everyone else in your household, and income from welfare benefits, dividends, and all other sources." Responses were measured in thousands of dollars, ranging from $0 to $999,000.[1] Although income was skewed, we chose to retain the raw values in analyses because extreme values are meaningful. Importantly, though, log transforming income did not alter any of the reported results.

3.2. Cognitive outcomes

Two cognitive processes were assessed in Wave IV (M_{age}=28.91) and thus examined in the present study.

3.2.1. Working memory

Working memory was assessed via a modified backward digit span task. The interviewer read each participant various strings of numbers of specific lengths, and participants were asked to repeat the list in reverse order. Participants were first read a two-number string and given two trials to correctly recall the string. If during either of those trials the participant correctly recalled the string (in reverse), the participant moved on to the next level. Each subsequent level presented participants with strings that were one number longer than the prior level. If a participant failed to recall the string in both trials for a particular level, the task ended. The highest level a participant was able to recall was recorded and used as the dependent variable. Working memory scores therefore ranged from 0 to 7, with higher scores representing a higher digit span and thus better working memory.

3.2.2. Long-term memory

Long-term memory was assessed via a word recall memory task. In particular, participants were read a sequence of 15 words, each separated by 1 s intervals. They were told to memorize those words for a memory test. Immediately after the words had been presented, participants completed an immediate recall task. Participants subsequently completed a questionnaire—consisting of eight questions about their feelings and how they compare to others—before being presented with a delayed recall test. Participants were given 60 s and asked to recall the 15 words they had previously encoded. The number of words recalled correctly at the delayed recall test was used as the measure of long-term memory in the present study.

3.3. Potential mediators

3.3.1. Perceived parental warmth

Perceived parental warmth was assessed during Wave II (M_{age}=16.54). Participants were asked whether they agreed with two statements: (1) "Most of the time [PARENT] is warm and loving toward you," and (2), "Overall you are satisfied with your relationship with [PARENT]." Participants answered both of these questions with regard to each of up to two parental figures, if applicable. Participants provided their responses to both of these questions using a five-point Likert scale that ranged from 1(*strongly agree*) to 5 (*strongly disagree*). Responses to these questions were averaged to create a parental warmth composite. Values were log transformed to correct excessive skew, but using the untransformed variables did not alter any of the results. Cronbach's alpha was acceptable, α =

[1] 588 participants in our sample (13.1% of participants with available income data) met criteria for poverty based on the 1995 poverty threshold, which was the most recent threshold during Wave 1

0.77, and removing any of the questions included in the scale reduced the scale's internal consistency.

3.3.2. Family education attitudes

Family attitudes toward education were assessed during Wave II (M_{age}=16.54). Participants were asked how disappointed their parent would be in two scenarios: (1) "they (participant) did not graduate high school" and (2) "they (participant) did not graduate college." Participants answered both questions with regard to each of up to two parental figures (e.g., mother and father), if applicable. Additionally, participants were asked to state how likely they felt it was that they would go to college, and how much they wanted to go to college, for a total of six questions in this scale. Participants provided their responses to these questions using a five-point scale, with 1 being low and 5 being high. Answers to these questions were averaged to create a family education attitude composite. Cronbach's alpha was acceptable, $\alpha = 0.78$, and removing any of the questions included in the scale reduced the scale's internal consistency.

3.3.3. Education attainment

Education attainment was assessed during Wave III (M_{age}=22.32). Participants were asked "What is the highest grade or year of regular school you completed?" Options ranged from "6th grade" to "5 or more years of graduate school" in one-year increments. Each option was given a numerical value, with higher values being given to higher levels of education (ranging from 1 = "6th grade" to 17 = "5 or more years of graduate school"), and the participant's numeric value was used as a continuous measure of education attainment in this study.

3.3.4. Stressful life events

Stressful life events were assessed across both Wave II and Wave III (M_{age} =16.54 and M_{age} =22.32 respectively). A pre-existing index of stressful life events in the Add Health dataset (Adkins, Wang, Dupre, van den Oord, & Elder, 2009) was modified to include a total of twenty-eight stressful life events, such as loss of a loved one, legal troubles, and exposure to violence (Table 1). The number of unique stressful life events a participant experienced was summed across Wave II and Wave III to create a cumulative stressful life experience (SLE) score.[2]

3.3.5. CRP

CRP was used as a biomarker of inflammation and assessed using a high-sensitivity assay—details of which have been published elsewhere (Harris, 2013). In brief, CRP was quantified from blood collected via dried blood spots (DBS), which were taken immediately after participants completed the study questionnaire. The DBS were stored in a − 70 °C freezer until the samples were assayed via an enzyme-linked immunosorbent assay (ELISA) (McDade, 2014) at the University of Arkansas, Department of Laboratory Medicine. Cross-validation using paired plasma samples and dried blood spots from a subset of 87 participants showed a strong correlation and linear association for the two collection methods, $r = 0.98$ (Harris, 2013). Sensitivity of the CRP assay was 0.035 mg/L; intra- and inter-assay coefficients of variation were 8.1% and 11%, respectively. CRP values were log transformed to correct for skewness, but using raw values did not alter the reported results.

3.4. Covariates

Demographic variables considered as covariates were self-reported age, self-reported race/ethnicity (dummy-coded contrasting Black/African American, Native American, Asian American, and Other with White as the reference group), and self-reported sex. Nondemographic covariates included in analyses were body mass index (BMI) at Wave IV and depression, which was measured by interviewers asking participants if a doctor or health care provider had ever diagnosed them with depression (coded as 1 =yes, 0 =no). These covariates were chosen because prior literature has found associations between them and our key variables of interest, including income, cognition, stress, and inflammation (Maydych, 2019; O'Neill, Kamper-DeMarco, Chen, & Orom, 2020; Yang, Shields, Guo, & Liu, 2018; Zimmerman & Katon, 2005).

4. Data analysis

To determine whether the factors previously discussed significantly mediated the association between family income in adolescence and either long-term memory or working memory, a multiple mediation model was created with perceived parental warmth, education attainment, family education attitude, stress, and CRP as potential mediators, income as the independent variable, and long-term memory and working memory as the two dependent variables. Covariances between each of the mediators and between each of the dependent variables were freely estimated. Models considering covariates controlled for sex, age, ethnicity, depression, and BMI to determine whether controlling for these variables changed any relations among the variables of interest. Analyses were conducted using R, version 4.0.2, and structural equation models were fit using the lavaan package, version 0.6–7. Missing data were estimated

[2] Additional stress measures were available in the Add Health dataset in both Wave III and Wave IV. The Wave III measure only asked participants if they had problems with severe stress or depression and if they were currently taking medication for stress of depression. The Wave IV measures consisted of two questions asking whether participants were relaxed and whether they were stress, along with the Perceived Stress Scale 4. Replacing the current stress measure with either of these measures resulted in stress no longer being a significant mediator of the income-long-term memory association.

Table 1
Stressful life events index.

Wave II and III Items	Wave II Items Only
Death of a parent	Had a serious injury
Suicide attempt resulting in injury	Father received welfare
Friend committed suicide	Mother received welfare
Family member committed suicide	Ran away from home
Saw violence	Non-physical abuse from a romantic partner
Threatened by knife/gun	Physical abuse from a romantic partner
Was shot	Non-physical abuse from a non-romantic sexual partner
Was stabbed	Physical abuse from a non-romantic sexual partner
Was jumped	**Wave III Items Only**
Threatened someone with knife/gun	Was evicted
Injured in a physical fight	Received welfare
Injured someone in a physical fight	Cohabitation ended
Unwanted pregnancy	Death of a romantic partner
Abortion, still birth, or miscarriage	
Had a child die	
Romantic relationship ended	
Contracted an STD	
Juvenile conviction	
Adult conviction	
Served time in jail	

using full information maximum likelihood.

5. Results

Demographic data for participants included in this study are provided in Table 2. Descriptive statistics and correlations among study variables of interest are provided in Table 3. On a bivariate level, most of our study variables of interest related to each other as expected (see Table 3).

Our primary analyses tested multiple potential statistical mediation pathways (i.e., via perceived parental warmth, education attainment, parental attitudes toward education, self-reported stress, and CRP) between adolescent income and both working memory and long-term memory in adulthood, controlling for covariates. Starting with the full model (Fig. 1), we removed the path or covariance with the largest p value (i.e., closest to one) sequentially until only significant paths and marginal paths ($p < .10$) were left in the model. This trimmed, final model was a good fit to the data, $\chi^2(29) = 22.65$, $p = .792$, CFI= 1.00, RMSEA< 0.001, SRMR= 0.007, as all indicated by fit statistics (e.g., the nonsignificant χ^2 indicates the model did not differ significantly from a fully specified model); removing the nonsignificant paths did not harm model fit. This model is depicted in Fig. 2. Income was a significant predictor of four of the five variables considered as potential mediators, $|\beta|s > 0.057$, $ps < 0.001$. Income was not a significant predictor of perceived parental warmth ($p = .284$ in the fully specified model), and this path was thus removed from the final model. However, many of these potential mediators did not relate to the cognitive outcomes as expected. In what follows, we first describe the tests of mediation for the adolescent income-adulthood working memory association, followed by the tests of mediation for the adolescent income–adulthood long-term memory association.

Three of the variables examined emerged as significant mediators of the adolescent income to adulthood working memory link. The first significant mediator was CRP: indirect effect= 0.004, $p = .035$, proportion mediated= 0.027. In detail, lower income was a significant predictor of higher CRP, $\beta = -.081$, $p < .001$, and higher CRP was a significant predictor of worse working memory, $\beta = -0.034$, $p < .018$. The second significant mediator of the income-working memory association was educational attainment: indirect effect= 0.080, $p < .001$, proportion mediated= 0.511. In particular, as expected, lower income was a significant predictor of lower educational attainment, $\beta = 0.240$, $p < .001$, and lower educational attainment, in turn was a significant predictor of worse working memory, $\beta = 0.218$, $p < .001$. Finally, even considering the significant covariance between educational attainment and family education attitude during adolescence ($\rho = 0.400$, $p < .001$), family education attitude during adolescence was an independent significant mediator of the income-working memory association, indirect effect= 0.014, $p = .004$, proportion mediated= 0.087. In particular, lower income was a significant predictor of lower family education attitude, $\beta = 0.171$, $p < .001$, and lower family education attitude was a significant predictor of worse working memory, $\beta = 0.052$, $p = .003$.,[34] Contrary to our expectations, neither stressful life events nor perceived parental warmth were significant statistical mediators of the adolescent income–adulthood working

[3] When excluding participants aged 18 years or older, family education attitudes ($p = .010$) remained a significant mediator of the income-working memory association, and perceived parental warmth remained nonsignificant in either mediation (data not shown).

[4] When using only the participants' own education attitudes, education attitudes remained a significant mediator of the income-working memory association ($p = .048$) and remained nonsignificant in analyses with long-term memory as the outcome. Similarly, when using only the participant's views of their parents' education attitudes, education attitudes remained a significant mediator of the income-working memory association ($p = .022$) and remained nonsignificant in analyses with long-term memory as the outcome

Table 2
Demographics of study sample.

Variable	*n*	%	Mean	*SD*
Age	6337		29.03	1.81
BMI	5042		29.14	7.49
Sex				
Male	3,051	48.1%		
Female	3,286	51.9%		
Race/Ethnicity				
Asian	209	3.3%		
Black	1485	23.4%		
Native American	71	1.1%		
Other	349	5.5%		
White	4,204	66.3%		
Missing/Refused	19	0.3%		
Depression				
Yes	827	13.1%		
No	4,286	67.6%		
Missing/Refund	1,224	19.3%		

Table 3
Descriptive statistics and Pearson's correlation coefficients among study variables.

Variable	*M*	*SD*	2.	3.	4.	5.	6.	7.	8.
1. Income Range: 0–999995 ($N = 4929$)	47,700.75	56,354.75	.049***	.104**,*	.025	.228**,*	.111***	-0.065***	-0.068***
2. Delayed Recall Range: 0–15 ($N = 5097$)	5.22	2.07		.256***	.034*	.193***	.121***	-0.004	-0.088***
3. Working Memory Range: 0–7 ($N = 5012$)	4.19	1.54			.018	.233***	.145***	-0.073***	-0.038**
4. Perceived Parental Warmth (ln) Range: − 1.61–0 ($N = 4694$)	-0.50	0.38				.050**	.154***	.022	-0.155***
5. Education Attainment Range: 1–17 ($N = 4824$)	8.21	1.99					.367***	-0.068***	-0.243***
6. Family Education Attitude Range: 1–5 ($N = 4814$)	4.27	0.85						-0.043*	-0.181***
7. CRP (ln) Range: − 2.50–5.32 ($N = 4545$)	0.77	1.35							.005
8. Stress Range: 0–21 ($N = 6504$)	1.76	2.25							

ln = log natural transformation. CRP = C-reactive protein.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

memory association (*ps* > 0.242 in the fully specified model) and were thus not included in the final model.

As for the adolescent income–adulthood long-term memory association, two significant mediators emerged. First, educational attainment was a significant mediator of this association, indirect effect= 0.094, $p < .001$, proportion mediated= 0.603. In particular, lower income was a significant predictor of lower educational attainment (described above), and lower educational attainment was a significant predictor of worse long-term memory, $\beta = 0.190$, $p < .001$. Additionally, stressful life events significantly mediated the association between income and adulthood long-term memory, indirect effect= 0.004, $p = .046$, proportion mediated= 0.023. In particular, lower income was a significant predictor of more stressful life experiences, $\beta = -0.057$, $p < .001$, and more stressful life experiences was a significant predictor of worse long-term memory, $\beta = -0.031$, $p = .023$. Contrary to expectations, CRP, family education attitudes, and perceived parental warmth were not mediators of the adolescent income–adulthood long-term memory association (*ps* > 0.135 in the fully specified model), and the nonsignificant paths were thus excluded from the final model.

5.1. Sensitivity analyses

We examined whether removing relevant covariates (i.e., age, sex, depression symptoms, BMI, race/ethnicity) from the model altered any of the above results. To test this, we re-ran the fully specified model without the previously mentioned covariates included. In this analysis, one result differed from what was described above. The mediation of the association between income and long-term memory by family education attitudes was now significant, indirect effect= 0.008, $p = .007$.

Additionally, because prior work has found that inflammatory activity influences the hippocampus, we conducted an additional analysis to determine if the link between CRP and working memory significantly differed from the link between CRP and long-term memory by constraining these paths to equality and comparing this model to the unconstrained model. In this analysis, the model

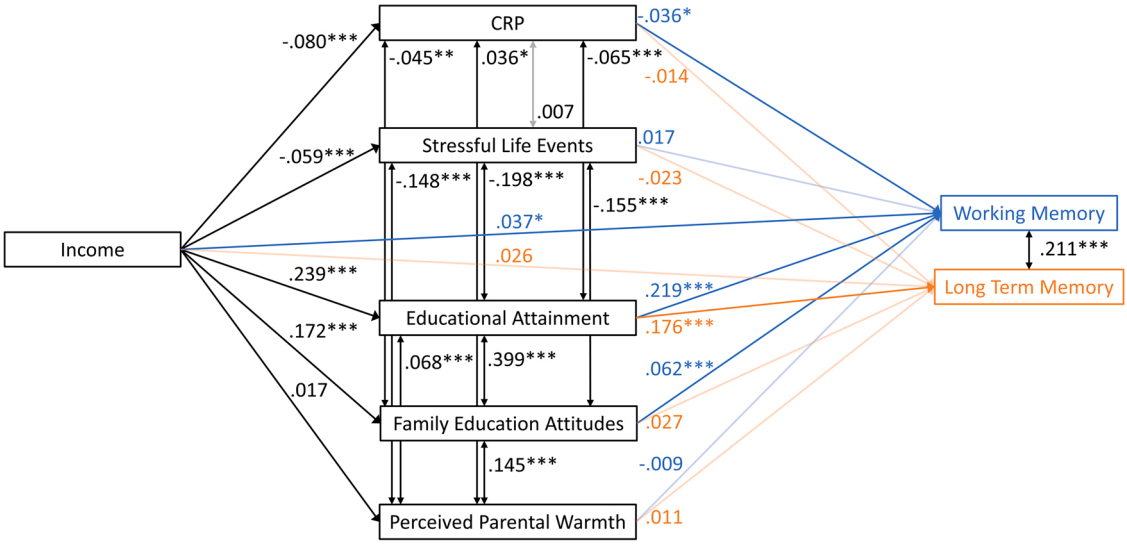

Fig. 1. Fully specified estimated mediation model examining potential mediators in associations between adolescent family income and adulthood cognition. All variables were regressed on all covariates (not shown). The link between income and working memory was significantly mediated by educational attainment, family education attitudes, and inflammation (CRP). The link between income and long-term memory was significantly mediated by educational attainment. ***$p < .001$, **$p < .01$, *$p < .05$.

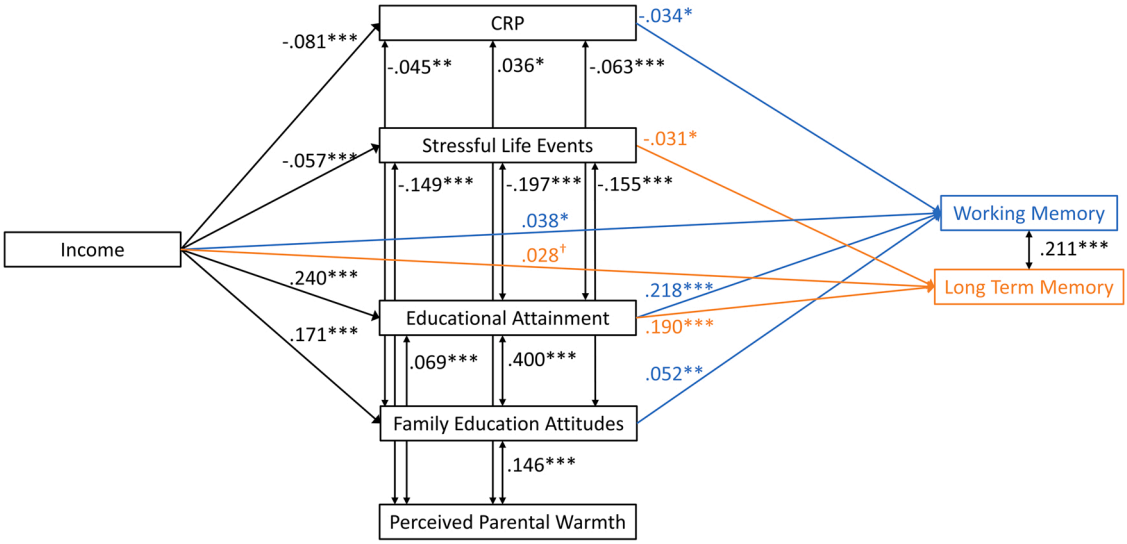

Fig. 2. Estimated mediation model examining potential mediators in associations between adolescent family income and adulthood cognition with non-significant, non-marginal pathways ($p > .1$) removed. All variables were regressed on all covariates (not shown). The link between income and working memory was significantly mediated by educational attainment, family education attitudes, and inflammation (CRP). The link between income and long-term memory was significantly mediated by educational attainment and stressful life events. ***$p < .001$, **$p < .01$, *$p < .05$, †$p < .10$.

constraining the path between CRP and working memory to equality with the path between CRP and long-term memory was a worse fit than the fully specified model without covariates, $\Delta\chi^2(1) = 9.97$, $p = .001$, suggesting that inflammation may be more strongly linked to working memory than long-term memory. However, this difference was no longer significant when covariates were included, $\Delta\chi^2(1) = 0.60$, $p = .439$.

Finally, examination of our income variable revealed outliers in income (see Fig. 3a). Because these income outliers reflect income inequality rather than measurement error, we chose to retain them in our primary analyses and examined residual covariances in our model; all |residual covariances were| $< \pm 0.10$. Nonetheless, we conducted sensitivity analyses by excluding participants whose adolescent family income was at or above the 99th percentile (i.e., ≥ $152,750) as well as a second analyses excluding participants whose adolescent family income at or above the 95th percentile (i.e., ≥ $80,000; see Fig. 3b). The only difference in these sensitivity

analyses was that stressful life experiences were no longer a significant mediator of the association between income and long-term memory for both models.

6. Discussion

The purpose of this study was to examine the statistical influences of multiple potential mediators in the relations between income and both working memory and long-term memory in a large longitudinal study. We found that both education attainment and family education attitudes mediated the associations between adolescent income and adulthood working memory and long-term memory. In addition, inflammation mediated the association between adolescent income and adulthood working memory in adulthood. These results therefore elucidate potential pathways through which adolescent income predicts adulthood cognitive functioning.

The strongest mediator found was education attainment, which statistically mediated the prospective associations between income and both working memory and long-term memory. Income is a barrier to higher education because of both the need for financial resources to pay for higher education and the importance of family attitudes towards pursuing higher education (Roksa & Kinsley, 2019). As a result, those with less income often find it more difficult to further their education from adolescence to young adulthood (Faas, Benson, & Kaestle, 2013). Education itself can improve both working memory and long-term memory (Orsini et al., 1986; Pressley, Borkwski, & Schneider, 1989; Ritchie & Tucker-Drob, 2018), which these results both support and extend by suggesting that the association between education and working memory is a pathway through which income predicts later working memory and long-term memory. This finding is further supported mechanistically by findings in the literature that education improves general cognition by training abstract reasoning skills and improving concentration and self-control (Ritchie & Tucker-Drob, 2018). Although

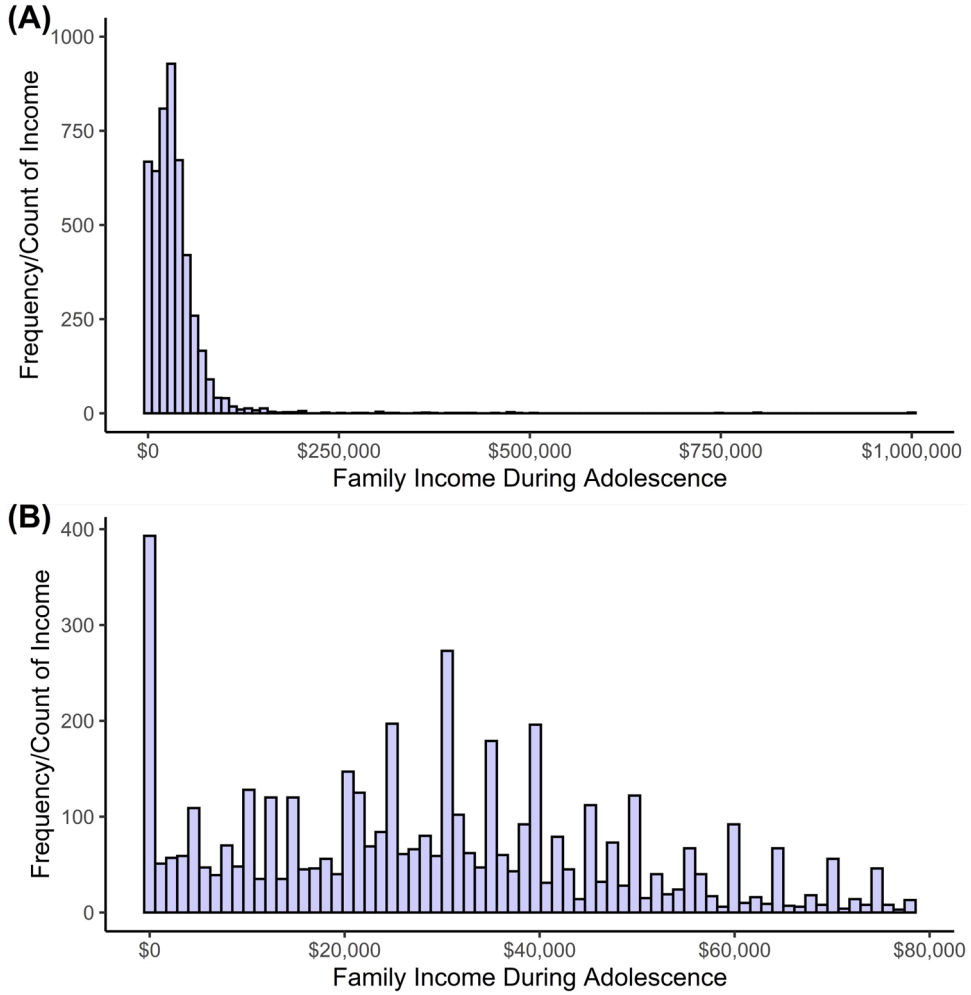

Fig. 3. Distribution of adolescent family income for our total sample. We conducted sensitivity analyses by excluding participants whose adolescent family income was at or above the 99th percentile (i.e., ≥ $152,750) as well as a second analyses excluding participants whose adolescent family income at or above the 95th percentile (i.e., ≥ $80,000). The only difference in these sensitivity analyses was that stressful life experiences were no longer a significant mediator of the association between income and long-term memory.

the socioeconomic benefits of increasing access to higher education are of course well understood (Ma, Pender, & Welch, 2016), our findings suggest that there may be psychological and cognitive benefits to improving access to education and thus educational attainment for low-income individuals.

In addition, family attitudes toward education also mediated income-cognition associations, with lower income predicting less positive family attitudes toward education, and less positive family attitudes toward education predicting poorer working memory and long-term memory. Notably, the covariance between family education attitudes and educational attainment was included in the model, entailing that this family education attitudes variable accounted for important variance even aside from its link with actual education achievement. Family attitudes towards education, which may be the results of specific barriers families with low-income face, may contribute towards discouraging higher education in their children. For example, parents with less income may be aware that they will not be able to afford college for their children. As a result, they tend not to push their children towards higher education (Davis-Kean, 2005) or even to excel in other schoolwork (Drummond & Stipek, 2004). Alternatively, less positive attitudes towards education could also reflect perceived failings of the local school systems in regard to their adolescents. If this is the case, interventions should target local schools rather than family attitudes. Additionally, low-income parents may not emphasize their child's academic achievements as much as high-income parents. Their children may interpret this lack of praise as them being less capable than other students, resulting in decreased reinforcement. No matter the mechanisms, little, if any, work had investigated how just family attitudes towards education predict cognition in adulthood. Our finding that family education attitudes partially mediated income-cognition associations provides a new avenue for understanding how income may influence cognitive development.

The mediation of the income–long-term memory association by stressful life experiences highlights the greater number of taxing experiences that individuals in low-income families often experience, and how those experiences may hinder memory later on in life. Although stressful life experiences are not unique to low-income families, low-income individuals are more likely to experience certain stressors throughout their lives, such as abuse, legal troubles, and parental separation (Merrick, Ford, Ports, & Guinn, 2018). Stress impairs long-term memory (Gianaros et al., 2007; Shields, Doty, et al., 2017; Shields, Sazma, et al., 2017; Wirkner, Ventura-Bort, Schwabe, Hamm, & Weymar, 2019), and low childhood socioeconomic status has been linked to abnormal hippocampus development through hair cortisol (Merz et al., 2019), which is a biomarker of chronic stress. Our work conceptually replicates this study and extends it by showing that low adolescent income through stress is linked not only to brain differences relevant to memory, but also to poorer long-term memory itself.

The lack of significance in the income-working memory association by stressful life experiences was contrary to expectations, as stress is known to impair working memory (Shields, 2020;; Shields, Spahr, & Yonelinas, 2020), in part by biasing cognitive processing towards salient environmental stimuli at the expense of executive control (Arnsten, 2015; Shields et al., 2016). Notably, other work has examined childhood income-related stressors and their associations with executive functions, and this work has found that these experiences mediate the association between socioeconomic disadvantage and executive functions (Blair, 2016). The discrepancy between our results and those obtained by Blair (2016) with regards to stressful life experiences as a mediator of income-working memory links could be taken to suggest that stressful experiences during childhood play a greater role in adulthood executive functions than similar experiences in adolescence.

Finally, inflammation (assessed via CRP) mediating the income-working memory association emphasizes the health risks that come with living in a low-income environment. Inflammation promotes states of rest in order to heal any injury or infection present (Dantzer & Kelley, 2007). Correspondingly, cognitive processes that would facilitate goal-oriented behaviors, such as working memory, are impaired (Miller & Spencer, 2014). Because there are multiple ways lower income can lead to increased inflammation—for example, financial stress, poor diet (supported by the influence of BMI in this study), pathogen exposure, and lack of healthcare (DeVoe et al., 2007; Goddard et al., 2020; Leung et al., 2014; Marks, 2007)—people can end up in a self-perpetuating trap of poverty (Shields, Deer, Hastings, & Hostinar, 2021; Shields, Moons, et al., 2017). That is, inflammation reduces executive cognitive capabilities (Teunissen et al., 2003), which hinders goal-oriented behaviors. If people's ability to focus on specific goals is hampered, they may face an additional obstacle to achieving academic and professional success, greatly reducing the possibility of increasing one's socioeconomic status, which in turn could lead to more inflammation. This reinforces the finding that inflammation mediates the income-working memory relationship.

Our results are appropriately contextualized by prior work on childhood income and adulthood cognition. Socioeconomic status during childhood has been found to be associated with neurocognitive functioning, particularly language skills and executive functions (). Furthermore, research conducted has examined mediators of the association between childhood socioeconomic status and executive function, with home environment being found to be a significant mediator (Sarsour et al., 2011). Our findings build upon these previous findings by extending our focus to adolescent family income rather than childhood family income. Income can vary considerably between childhood and adolescence (Deer et al., 2021), and adolescence is an especially sensitive time period in regards to the influence of environmental factors on cognitive functions (Guyer, 2020; Shields, Moons, et al., 2017). Furthermore, our findings expand previous work on mediators of the association between income and cognition in general with the significance of education attainment and family education attitudes as mediators building upon previous studies that focused on home environment and stress.

This study has a few limitations that should be noted. First, data for perceived parental warmth and family education attitudes were taken from Wave II interviews. Wave II participants had a mean age of 16.54 years ($SD = 1.60$), with approximately 79% of participants age 18 or younger (94% age 19 or younger). Because of this, measures of perceived parental warmth and family education attitudes for these participants can be considered prospective, though for other participants, these measures may have been retrospective. Second, as this was a secondary analysis of a national dataset, we were unable to directly control any data collection methods. As a result, certain variables that may have been more appropriate to use (i.e., income to needs ratio) were not available for analysis. Third, the perceived parental warmth scale consisted of only two items, which could potentially be problematic. However, many

acceptable scales only have one or two items (Ehrhart et al., 2009; Konrath, Meier, & Bushman, 2014), and our parental warmth scale achieved acceptable reliability ($\alpha = 0.77$). Fourth, data for the perceived parental warmth and the family education attitudes variables required participants to report on their perceptions of their parents' opinions. Although there may be objective differences between how attitudes are perceived and the views parents actually hold, subjective perceptions are usually more influential than objective situations (Slavich & Cole, 2013). Moreover, results did not differ when only participants' own attitudes towards education were used as the mediator. Fifth, we were unable to control for general cognitive ability in our analyses, as Add Health does not have a measure of general cognitive ability. However, it should be noted that our model estimated the covariance between working memory and long-term memory to control for general cognitive ability inasmuch as it is shared by these two cognitive constructs. Thus, although we were unable to control for general cognitive ability per se, the high overlap between long-term memory performance or working memory and measures of general cognitive ability help to determine relatively unique associations with each cognitive construct given their estimated covariance. Sixth, as shown in Table 3, some correlations among variables of interest were small in magnitude. Nonetheless, even small associations with these cognitive processes are potentially impactful, given the importance of these cognitive processes to a variety of outcomes related to academic achievement, career success, and quality of life (Diamond, 2013; Gioia et al., 2010). For example, our data suggested that for every standard deviation decrease in yearly family income during adolescence, working memory declined by 0.104 standard deviations. Working memory declines of this magnitude would be expected to predict declines in academic achievement by 0.046 standard deviations (Gathercole, Pickering, Knight, & Stegmann, 2004) and quality of life by 0.048 standard deviations (Brown & Landgraf, 2010). As such, while these income-cognition associations may be small, they are important. Finally, the only variable of interest with information available at all points of time was the parental warmth composite. All other variables of interest were only available at a single point in time—with the exception of the stressful life events variable, which was taken from experiences across Waves II and III. This may result in the paths in our mediation model over- or underestimating relative to their true values (Selig & Preacher, 2009). Additionally, being unable to examine change over time reduces statistical power and precludes stronger tests of temporal precedence.

Despite these limitations, this study adds important knowledge to income and cognition research while also offering avenues for novel interventions. The significance of educational attainment as a mediator emphasizes the need for more programs that make higher education accessible for more low-income families, such as scholarships for low-income individuals or more lenient student loan programs. The implementation of these programs could potentially result in a shift in attitudes towards higher education in low-income parents, as their financial situation would no longer make college an impossibility for their children, which would help reduce the effects of family education attitude as a mediator of the income-working memory association. Finally, the significance of both CRP and stressful life experiences illustrates the need for multiple programs to aid low-income families, including increased access to healthcare, stress-management classes, resources to help improve diet, and financial aid for families in need.

7. Conclusion

The findings of this study demonstrate the wide-ranging longitudinal consequences of low adolescent income, and how persistent the cognitive sequelae low income can be. Through a combination of less positive family attitudes toward education, lower education attainment, more stress, and greater levels of inflammation, low adolescent family income predicts poorer long-term and working memory in adulthood. These deficits create a vicious cycle of sorts, putting more and more barriers to increasing one's socioeconomic status, which in turn may worsen cognitive functioning. Although low family income appears to exert numerous detrimental effects, it may be possible to mitigate some of those effects by intervening on education attainment, family education attitudes, stress, and inflammation.

Declarations

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Authors contributions

C. L. Hunter developed the study concept. All authors contributed to the study design. Testing and data collection were performed by the Add Health team. C. L. Hunter performed the data analysis and interpretation under the supervision of G. S. Shields. C. L. Hunter drafted the manuscript, and G. S. Shields provided critical revisions. All authors approved the final version of the manuscript for submission.

Disclosure of interest

The authors declare no conflicts of interest with respect to the authorship or publication of this article.

Availability of data and materials

All data used in this study are freely available from the Add Health website at https://addhealth.cpc.unc.edu/data/. Materials are available from either author upon request.

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