Article

Sex Differences in the Association between Household Income and Children's Executive Function

Shervin Assari [1],* , **Shanika Boyce [2]**, **Mohsen Bazargan [1,3]** and **Cleopatra Howard Caldwell [4]**

[1] Department of Family Medicine, Charles R. Drew University of Medicine and Science, Los Angeles, CA 90059, USA; Mohsenbazargan@cdrewu.edu

[2] Department of Pediatrics, Charles R. Drew University of Medicine and Science, Los Angeles, CA 90059, USA; ShanikaBoyce@cdrewu.edu

[3] Department of Family Medicine, University of California Los Angeles (UCLA), Los Angeles, CA 90095, USA

[4] Department of Health Behaviors and Health Education, University of Michigan, Ann Arbor, MI 48109, USA; cleoc@umich.edu

* Correspondence: assari@umich.edu; Tel.: +734-232-0445; Fax: +734-615-8739

Abstract: The study aimed to investigate sex differences in the boosting effects of household income on children's executive function in the US. This is a cross-sectional study using data from Wave 1 of the Adolescent Brain Cognitive Development (ABCD) study. Wave 1 ABCD included 8608 American children between ages 9 and 10 years old. The independent variable was household income. The primary outcome was executive function measured by the stop-signal task. Overall, high household income was associated with higher levels of executive function in the children. Sex showed a statistically significant interaction with household income on children's executive function, indicating a stronger effect of high household income for female compared to male children. Household income is a more salient determinant of executive function for female compared to male American children. Low-income female children remain at the highest risk regarding poor executive function.

Keywords: executive function; socioeconomic status; children; household income

1. Introduction

Among the most salient social determinants of children's behavioral and developmental outcomes is socioeconomic position (SEP) [1–3]. Among various SEP indicators is household income, which is one of the most influential social determinants of children's outcomes across domains [4–7]. Families with high-income report higher levels of parental involvement, which boosts a wide range of children's desired outcomes [8–12].

Household income is a predictor of a wide range of positive children's behavioral outcomes [4–7]. Children from high-income families are less likely to experience various types of stress and associated behavioral and health problems [13–15]. Income may partially explain some of the existing gaps in children's behavioral outcomes between marginalized and privileged groups [16–19]. If income is partially responsible for the existing gaps, then reducing the income gap through income redistribution policies and empowering marginalized groups to secure more income should be regarded as the primary strategy for addressing the social inequalities that we observe between social groups [20,21].

Suppose income has differential effects on the outcomes of various sub-groups. In that case, income may also operate as a source, rather than a solution, of the existing inequalities [22,23]. The marginalization-related diminished returns (MDRs) literature shows that household income and other SEP indicators [24] generate unequal outcomes for racial and ethnic subgroups. As shown by

the MDRs [25,26], social marginalization reduces the impact of SEP indicators such as income on generating tangible behavioral outcomes. For example, children who are members of a disadvantaged group show weaker effects of household income and other SEP indicators on children's behavioral outcomes. The same is shown for race [25,26], ethnicity [24,27,28], sexual orientation [29], nativity [23], place [30], and sex [31,32]. In all these cases, the socially marginalized group shows weaker effects of income and other SEP indicators on behaviors [24]. Any marginalized group may face more difficulties leveraging their resources and working with social systems to secure measurable and desirable behavioral outcomes when SEP indicators such as education are available [26]. For example, marginalized groups gain less from their existing resources.

Some research has shown that SEP indicators may have some sex-specific effects on brain function [33]. Javanbakht et al. (2016) [34] and Kim et al. (2018) [35] found larger effects of household income on the brain function of female children than male children; Whittle and colleagues (2014) [36] and McDermott and colleagues (2019) [37] showed boys to be more sensitive than girls to a variety of environmental inputs. Thus, while sex differences in SEP effects on brain development are likely, the direction of these sex differences may depend on brain structure and function. The literature seems to be mixed on this matter.

Executive function is a set of mental skills that include working memory, flexible thinking, and self-control [38,39]. While memory and flexible thinking reflect other dimensions of executive function, response time, correct go responses to "go signals", and correct stops to stop signs all reflect a domain of executive function that is associated with motor control, inhibiting, impulsivity, and response time [40–44]. Executive "brake failure" following executive control of response inhibition as well as the fast response to the go signals all reflect aspects of executive function [45,46]. These aspects of executive function can be measured using Stroop task [47], go/no-go [48–50], and stop-signal task [45,46]. While trauma reduces executive function [51], high SEP is closely associated with better executive function [38,52]. Executive function may mediate the effect of SEP on school performance and cognitive performance. Similarly, executive function reflects structure and functional aspects of the brain cortex and white matter [44,53,54]. To give examples, executive function is linked to cortical thickness [41,55], cortical function [53], white matter structure and volume [44,53,54], and functional connectivity between various brain regions, and cortex [42].

Aims

In this investigation, we compared male and female children for the effects of household income on children's executive function. While high household income was expected to be associated with higher executive function, this effect is expected to be more salient for males than females. The male sex was conceptualized as an indicator of social privilege. Stronger effects of SEP indicators for males than females were shown by Whittle and colleagues (2014) [36] and McDermott and colleagues (2019) [37].

2. Materials and Methods

2.1. Design, Setting, and Sampling

This cross-sectional study was a secondary analysis of existing data. We borrowed data from the Adolescent Brain Cognitive Development (ABCD) study [56–60]. The ABCD is a national children's brain development study with a broad sample, diversified based on race, ethnicity, sex, and SEP [56,61].

Participants were recruited from multiple cities across various states in the US. This sample was enrolled through the US school system. The recruitment catchment area of the ABCD, which was composed of 21 participating sites, encompasses more than 20% of the entire United States population of 9–10-year-old children. The ABCD applied a carefully designed sampling and recruitment process across various sites, described elsewhere [56,57,59,61–74], to ensure that the sample is random and representative. Such local randomization efforts yielded a final overall ABCD sample that is a close approximation of national sociodemographic factors. These sociodemographic factors include race and

ethnicity, age, sex, SEP, and urbanicity. The SEP target in the ABCD has two sources: (1) the American Community Survey (ACS) and (2) annual 3rd and 4th-grade school enrollment. A full description of the ABCD sample and sampling is published here [75]. The first is a large-scale survey of approximately 3.5 million households conducted annually by the US Census Bureau. The second data is maintained by the National Center for Education Statistics (NCES), which is affiliated with the US Department of Education.

Analytical Sample

This study included 7920 non-twin 9–10-year-old children who had data on income and executive function. Children from any race or ethnicity were included.

2.2. Measures

2.2.1. Outcome

Executive function. This variable was operationalized as rate of correct "go" in the runs (average of run 1 and run 2). This variable is named *tfmri_sst_all_beh_correct.go_rate* in the DEAP system. Executive function in this study was treated as a continuous measure, with a higher score being an indication of a higher executive function. Figure 1 shows the distribution of the outcome.
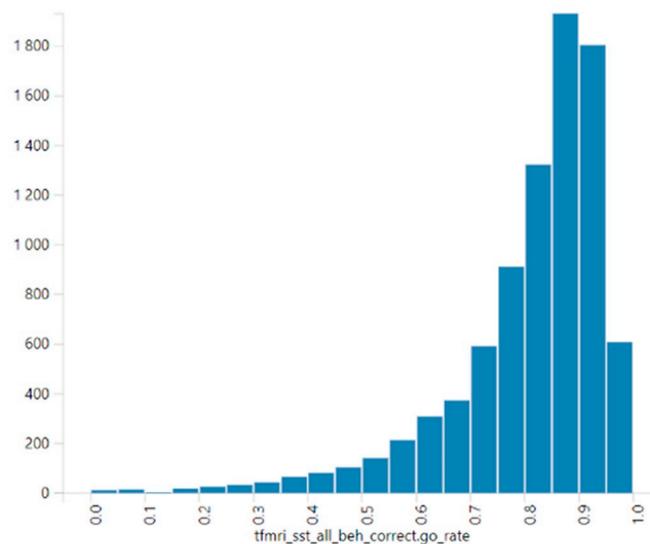

Figure 1. Distribution of the outcome.

2.2.2. Moderator

Sex. Sex, 1 for males and 0 for females, was a dichotomous variable. This variable was the effect modifier.

2.2.3. Independent Variable

Household income. Household income was a three-level categorical variable. The item used to measure household income was "What is your total combined household income for the past 12 months? This should include income (before taxes and deductions) from all sources, wages, rent from properties, social security, disability and veteran's benefits, unemployment benefits, workman". Responses included 1 = less than $50,000; 2 = $50,000 to $99,000; 3 = $100,000 or more. Distribution of our household income variable is shown in Figure 2.
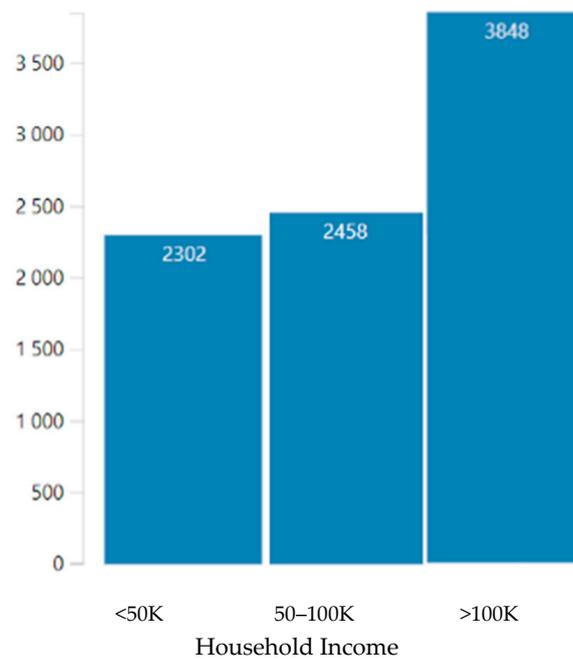
Figure 2. Distribution of household income.

2.2.4. Confounders

Race [76,77], ethnicity [78], age [79], and parental marital status [39] were the confounders. These confounders were selected based on a literature review [38,52].

Race. Race, a self-identified variable, was a categorical variable with the following options: Black, Asian, Other/Mixed Race, and White (reference group). Racial variation in executive function is well described [78].

Ethnicity. Ethnicity was also a self-identified variable and a categorical variable: Hispanics vs. non-Hispanics (reference category). Age was a dichotomous measure with a response of either 9 or 10 (years old). Ethnicity is shown to have an impact on executive function [78].

Age. Parents reported the age of the children. Age is a predictor of executive function [79].

Parental marital status. Marital status of the household was a dichotomous variable: married = 1 and non-married = 0. Family structure and marital status of the parents are shown to predict children's executive function [39].

2.3. The Stop Signal Task (SST)

The SST is most appropriate for evaluation of core brain regions and networks that are involved in the domains of impulsivity and impulse control. The SST, however, also measures attention, executive function, and memory. These brain functions have major implications in cognitive disorders, ADHD, learning disorders, and addiction effects. These tasks are also well validated in adolescents. The SST measures how well a participant withholds or interrupts a motor response to a "go" signal when he or she unpredictably faces a "stop" signal. The ABCD SST is composed of 2 runs each contain 180 trials. Each trial starts with an instruction that includes the presentation of leftward or rightward pointing arrows. Participants are asked to indicate the direction of the arrows, while responding "as quickly and accurately as they can". These responses should be using a two-button response panel. A total number of 30 trials (16.67%) are "stops". More information on the ABCD SST is available elsewhere [57].

2.4. Data Analysis

2.4.1. Main Analysis

To describe our sample, we reported mean (SD) for continuous variables and frequencies and percentages for categorical variables in the pooled sample and by age. We also used Chi square or independent sample *t* test to compare male and female children for the study variables. Our main analysis applied mixed (random) effect models that allowed adjusting for the nested nature of the data. This analysis was performed in the Data Analysis and Exploration Portal (DEAP), National Data Archive (NDA), National Institutes of Health (NIH). Participants were nested within families who were nested within 21 sites. As such, our models corrected for non-independence of our observations. To conduct mixed effect multivariable analysis, two models were performed. In both of these models, executive function was the outcome, sex was the moderator, household income was the predictor, and covariates (ethnicity, age, and parental marital status) and site ID and family ID were controlled. Both of these mixed effect models were estimated in the overall/pooled sample. *Model 1 (no interaction)*, the main effect model, was estimated in the absence of the household income by sex interaction term. *Model 2 (the interaction model)* added an interaction term between sex and household income. Appendix A shows the *Model 1* and *Model 2* in the DEAP system. Regression coefficient (b), SE, and *p*-values were reported for each model. Graphs reflecting these results were also shown.

2.4.2. Ethical Aspect

For this study, we used a fully de-identified data set. As such, this study was exempt from a full review of the Institutional Review Board (IRB number 1665000-1). However, the protocol of the main study, the ABCD, was approved by the IRB at the University of California, San Diego (UCSD), and several other institutions. Participants signed consent or assent depending on their age [61].

3. Results

Table 1 depicts the summary statistics of the pooled/overall sample. The current analysis was performed on 8608, 9–10-year-old children of whom 51% were male and 49% were female.

Table 1. Descriptive data overall and by sex (*n* = 8608).

Characteristics	All 8608 Mean (SD)	Female 4220 Mean (SD)	Male 4388 Mean (SD)	*p*
Age	119.18 (7.46)	118.94 (7.44)	119.40 (7.46)	0.004
Executive function (mean (SD))	0.81 (0.15)	0.81 (0.15)	0.81 (0.14)	0.471
Household income	*n* (%)	*n* (%)	*n* (%)	
<50 K	2302 (26.7)	1161 (27.5)	1141 (26.0)	0.231
≥50 K & <100 K	2458 (28.6)	1205 (28.6)	1253 (28.6)	
≥100 K	3848 (44.7)	1854 (43.9)	1994 (45.4)	
Race				
White	5891 (68.4)	2833 (67.1)	3058 (69.7)	0.073
Black	1129 (13.1)	578 (13.7)	551 (12.6)	
Asian	186 (2.2)	99 (2.3)	87 (2.0)	
Other/Mixed	1402 (16.3)	710 (16.8)	692 (15.8)	
Sex				
Female	4220 (49.0)	4220 (100.0)	0 (0.0)	<0.001
Male	4388 (51.0)	0 (0.0)	4388 (100.0)	
Married family				
No	2463 (28.6)	1252 (29.7)	1211 (27.6)	0.036
Yes	6145 (71.4)	2968 (70.3)	3177 (72.4)	
Hispanic				
No	6998 (81.3)	3420 (81.0)	3578 (81.5)	0.572
Yes	1610 (18.7)	800 (19.0)	810 (18.5)	

Table 2 provides a summary of our two mixed-method regression models that adjusted for the nested nature of the data. Both models were in the overall (pooled) sample. *Model 1* (main effect model) showed an effect of household income on executive function. *Model 2* (interaction model) showed an interaction term between sex and household income on executive function, suggesting that the effect of household income on executive function was weaker for males than females.

Table 2. The results of mixed effect models that adjusted for nested data.

Characteristics	Estimate	Std. Error	t	p	Sig.
Model 1					
Household income [≥100 K]	0.02987	0.00484	6.18	$<10^{-6}$	***
Household income [≥50 K & < 100 K]	0.02013	0.00466	4.32	1.55×10^{-5}	***
Model 2					
Household income [≥100 K]	0.04250	0.00611	6.95	$<10^{-6}$	***
Household income [≥50 K & < 100 K]	0.02528	0.00620	4.08	4.62×10^{-5}	***
Sex (Male)	0.01413	0.00587	2.41	0.0161502	*
Household income [≥100 K] × Male	−0.02507	0.00745	−3.37	0.0007673	***
Household income [≥50 K & < 100 K] × Male	−0.01061	0.00820	−1.29	0.1958092	-

Age, marital status, race, and ethnicity are controlled in both models. * $p < 0.05$; *** $p < 0.001$.

Figure 3 shows an effect of household income on executive function in the pooled sample. As this figure shows, there was a stepwise association between household income and children's executive function, with children from families with a household income of more than 100,000 USD showing the highest levels of executive function, children from families with a household income between 50,000 and 100,000 showing the second highest executive function, and children from families with a household income less than 50,000 showing the lowest level of executive function.
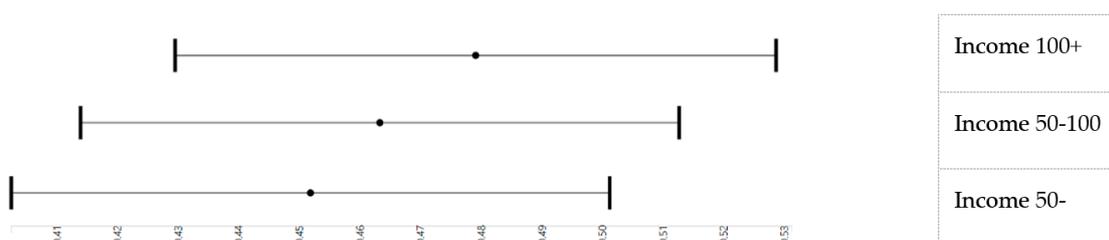

Figure 3. Association between household income and children's executive function.

Figure 4 shows an interaction between household income and executive function in the pooled sample. As this figure shows, gain in children's executive function due to high household income was smaller for male than female children.
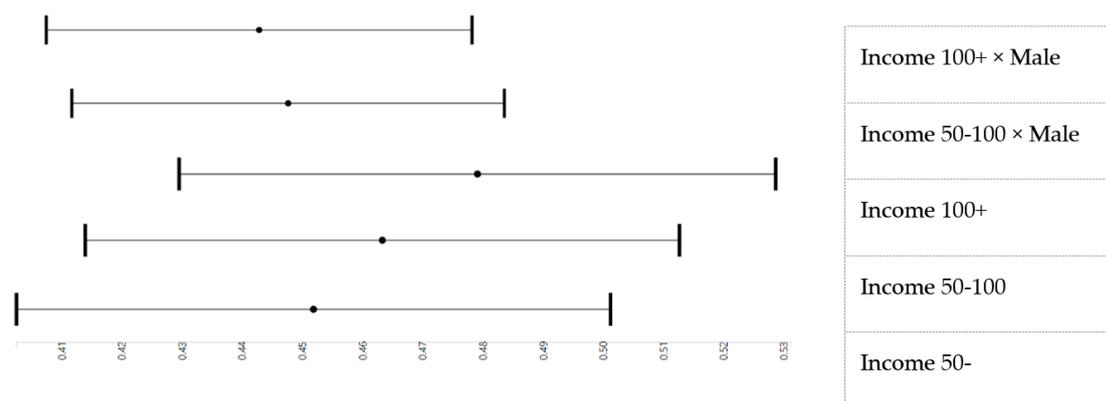
Figure 4. Association between household income and children's executive function by child sex.

4. Discussion

Our findings showed that sex alters the effects of household income on children's executive function, with stronger effects of household income being observed for female than male American adolescents. Our replication findings also confirmed our primary modeling. These results can be explained via the effects of sex, a biological construct that reflects differential brain development due to sex hormones or genetics, or the effects of gender, a social construct that reflects differential socialization of girls and boys in society.

Sex differences may explain the results. Environmental input, including variation in SEP, may have some sex-specific effects on brain structure and function [33]. A study showed that SEP indicators such as income may have a larger effect on brain structures (e.g., amygdala) of females than males [34]. Another study found that household income was associated with an increase in the structural brain network efficiency of female but not male children aged 6–11 years old [35]. Some other studies have provided the opposite results. Another study documented a stronger effect of SEP on the shape of the cortical surface of males than females [37]. A study showed that positive parenting and caregiving better predict the volumetric growth of the amygdala and the cortical thinning of the right anterior cingulate for boys than girls [36]. Thus, although sex differences may exist in the effects of environment and SEP on brain development, the directions of these sex differences are inconsistent [80].

Gender differences, the difference in the social experiences of males and females, may also explain the findings. Gender differences may be caused by social networks, culture, norms, parents, and friends. It is possible that the impact of parents, teachers, and peers differ across SES levels for boys and girls. Similarly, it is likely that SEP has a larger impact on opportunities and experiences of girls than boys. While boys of high- and low-income families similarly develop, high- and low-income girls experience vastly different effects of parenting, stress, peers, and social risk. How parents socialize or monitor their boys and girls widely varies [81–83]. The influence of peers also varies for boys and girls [84]. Finally, males and females use different coping mechanisms [85]. These may all result in gender differences in the effects of SES on daily experiences and exposures that shape brain development and executive function.

Sex and gender differences are neither specific to an age group (children), an SEP indicator (income), or a behavioral outcome (executive function). That means sex and gender differential effects of a wide range of SEP indicators on many outcomes have been documented for children, adults, and older adults. Among adults, many studies have shown stronger health effects of income and other related SEP indicators for males than females [86–90].

4.1. Future Research

We argue that studies on behaviors or development should not merely control for gender/sex. This is particularly true for studies investigating how SEP indicators shape neural, behavioral, and

social development of diverse groups of children. Most of the research has traditionally "controlled" for the statistical effect of sex or gender. Researchers should be aware that sex/gender may also alter SEP indicators' effect on behaviors and brain function and development.

4.2. Future Research

Additional research is needed on parental, social, psychological, and even biological mechanisms that may explain why child gender or sex interfere with SEP indicators such as income on executive function. According to the social reproduction theory, parental SEP may differently impact children's developmental and behavioral outcomes across social groups [91]. Furthermore, not only sex but the intersection of race, sex, place, and class may shape the outcomes of children in the US [92]. These, however, require further research.

4.3. Methodological Limitations

A limitation of this study is the cross-sectional design. This study only investigated the MDRs of one SEP indicator, namely household income. It is unknown if there are differential marginal returns of other SEP indicators such as wealth, parental education, parental marital status, employment, and even higher-level SEP indicators such as neighborhood SEP. In addition, recall bias may have affected our variable household income, which was self-reported. Marital status, our confounder, also only had two categories of married and unmarried. More nuanced measurements of marital status of the family, and separating never married, partnered, and divorced families could shed more insight on the details of how and when family structure influences children's brain development. Future research may study peer influences, norms, expectations, parenting, and sex hormones to explain why household income influences male and female children differently.

5. Conclusions

High household income shows a greater influence on the executive function of girls than boys. This means that girls from low-income families would have the poorest executive function. However, boys with high and low incomes do not vary much in their executive function.

Appendix A. Model Formula for Our Models

Variable Names in DEAP	Study Constructs
Model 1	*Model 1*
tfmri_sst_all_beh_correct.go_rate ~ household.income.bl + race.4level + sex + married.bl + age + hisp Random: ~(1|abcd_site/rel_family_id)	Executive function = household income + race + sex + married + age + Hispanic Random: Site + Family
Model 2	*Model 2*
tfmri_sst_all_beh_correct.go_rate ~ household.income.bl + race.4level + sex + married.bl + age + hisp + household.income.bl * sex Random: ~(1|abcd_site/rel_family_id)	Executive function = household income + race + sex + married + age + Hispanic + household income x race Random: Site + Family

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