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# The Relationship Between Economic Deprivation and Emerging Inhibitory Control in Young Children

A Thesis Submitted to the

Yale University School of Medicine

in Partial Fulfillment of the Requirements for the

Degree of Doctor of Medicine

by

Rachel Scott Weston

2009

Abstract

THE RELATIONSHIP BETWEEN ECONOMIC DEPRIVATION AND EMERGING INHIBITORY CONTROL IN YOUNG CHILDREN. Rachel S. Weston, David J. Bridgett, Linda C. Mayes. Yale Child Study Center, Yale University School of Medicine, New Haven, CT.

An extensive body of research has documented detrimental effects of growing up in poverty on children's global cognitive development, particularly when economic deprivation occurs in early childhood. However, little is known about the impact of poverty on children's component neurocognitive capacities. The prefrontal cortex is one brain region, responsible for the executive control functions, that has a prolonged period of postnatal development and therefore may be especially susceptible to environmental influences like poverty. Inhibitory control is an important executive function to investigate because it appears to be a significant predictor of language and math skills in preschool and later school years. In the current study, we hypothesized that children living in more economically disadvantaged families would have delayed development of their inhibitory control abilities and would have altered developmental trajectories with increasing developmental lag compared to children living in more economically advantaged families. The current study employed latent growth curve modeling to model the developmental trajectories of inhibitory control for a cohort of 125 children followed longitudinally between ages 5 and 8. Commission errors from a picture AX Continuous Performance Task were used to measure inhibitory control. Consistent with

developmental expectations, we found that as children get older, they make progressively fewer inhibitory control errors (age 5 mean = 19.86 vs. age 8 mean = 4.76). Significant interindividual differences were also present in both slope and intercept factors. Adding child gender and income-to-need ratio at age 5 to the model as predictors, we found that both factors accounted for significant interindividual differences, together explaining 12 percent of the variance in the intercept (i.e., 5-year-old inhibitory control ability). This predictor model provided an excellent fit for the data. At age 5, male children made more inhibitory control errors than female children. Also, children from more economically disadvantaged families made more inhibitory control errors than their peers from more advantaged families. An unexpected finding was that child gender and income-to-need at age 5 did not account for significant interindividual differences in trajectory slope (i.e., no developmental lag was observed). These results suggest that the impact of economic deprivation on prefrontal cortex development and subsequent development of inhibitory control occurs early (before age 5), putting children on a particular trajectory based on this early exposure to poverty. Tailoring interventions (e.g., early education programs) to reinforce executive functions like inhibitory control below the age of 5 years could potentially maximally improve cognitive outcomes among low-income children.

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## Introduction

In 2007 the official poverty rate in the United States was 12.5 percent, with 37.3 million people living in poverty.[1] In the same year, the number of children living in families whose income failed to exceed official poverty thresholds was 13.3 million or 18 percent. Children are therefore disproportionately living in poverty, representing 35.7 percent of the people in poverty but only 24.8 percent of the total population (1). Living in poverty has been hypothesized to influence child outcomes through many mechanisms. These include inadequate nutrition, instability of residence, lower quality schools, fewer learning opportunities both inside and outside of the home, increased exposure to environmental toxins, increased family stress and cortisol release, and increased exposure to violence (2-5).

An extensive body of research has documented detrimental effects of growing up in poverty on children's development. These studies have consistently found negative associations between poverty and a range of child outcomes, including physical health, socio-emotional development, and cognitive development (for reviews, see (2-4, 6)). Physical health outcomes associated with poverty include higher rates of delivery of low birth weight infants, growth stunting, asthma, iron deficiency, and lead poisoning (2, 3, 7). Emotional and behavioral outcomes that have been associated with poverty include higher rates of externalizing behaviors such as aggression and acting out and internalizing behaviors such as anxiety and depression (2, 8).

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[1] In 2007, the official definition of poverty in the United States was an annual income of less than \$21,203 for a family of four (1).

Cognitive development is particularly important because it is connected to the level of success a child will experience later in life, including the child's potential economic contribution to society. Researchers have documented associations between economic disadvantage and poorer performance on a variety of measures of young children's cognitive development and achievement outcomes. These measures include IQ (9-14), language development (13), school readiness (13), achievement test scores (11, 12, 15), prevalence of learning disabilities (2), and rates of grade repetition and high school dropout (2). Among low-income children, cognitive delays in tests of intelligence appear as early as age 2 (11, 14). Specifically, one longitudinal study found that children in families with incomes below 50 percent of the poverty threshold had scores between 6 and 13 points lower on tests of IQ, verbal ability, and school achievement compared with children from families with incomes between 150 and 200 percent of the threshold (11). Research has also shown that mild mental retardation is more prevalent among poor children, whereas moderate and severe mental retardation are fairly evenly distributed among socioeconomic groups (7).

Additional research has examined how the duration and timing of poverty might impact children's cognitive development. Many studies have demonstrated that persistent, unremitting poverty over many years has a stronger negative association with children's cognitive outcomes than transient poverty (9, 11, 13). In addition, family economic conditions in early childhood appear to have the strongest effect on children's cognitive outcomes (5). Specifically, family income between birth and age 5 has a much stronger effect on school years completed than income measured at older ages. In fact, among low-income children, an increase in mean family annual income of $10,000 during a child's first five years of life is associated with almost one additional year of completed schooling and three times the odds of finishing high school (5).

Yet despite this extensive body of research correlating economic disadvantage with negative effects on children's cognitive development, more research is needed to provide information about possible brain-based mechanisms through which poverty might affect cognitive outcomes. Little is known about the impact of poverty on children's component neurocognitive capacities.

Research has clearly demonstrated that children's experiences affect brain development (16, 17). Neurocognitive systems that have prolonged periods of postnatal development may be especially susceptible to environmental influences like poverty. The prefrontal cortex (PFC) is one such brain region that is responsible for the executive control functions (18), broadly defined as a set of cognitive skills that are responsible for the planning, initiation, sequencing, and monitoring of complex, goal-directed behavior (19). Many researchers have described three core components of executive functioning: inhibitory control, working memory, and shifting of attention to changing demands (cognitive flexibility) (20-22). Confirmatory factor analysis has shown that these three components are clearly distinguishable, though not completely independent (20). Some have theorized that the unity among the executive functions could be accounted for by inhibitory control, as all three executive functions require some inhibitory processes to operate properly (e.g., ignoring irrelevant incoming information in working memory tasks or ignoring the no longer relevant rules in cognitive flexibility tasks) (20, 23).

Inhibitory control is therefore an important component of executive control function, which appears to emerge gradually from preschool to early school age (18, 24).

Inhibitory control involves both inhibition in attention (the ability to selectively attend to relevant stimuli while ignoring distractors) and inhibition in action (the ability to selectively respond to relevant stimuli while suppressing prepotent responses to irrelevant stimuli). Research has shown that the period from 3.5 to 7 years of age is a time of significant improvements on many different cognitive tasks reflecting PFC functioning that require working memory and inhibition (18). These functional changes parallel striking anatomical and biochemical changes in PFC, especially dorsolateral PFC, the sub-region thought to be most responsible for working memory and inhibitory control. These biological changes include significant decreases in neuronal and synaptic density, expansion of pyramidal cell dendritic trees, and vastly increased myelination of axonal projections (18).

Inhibitory control is vital to a child's ability to attend, sort relevant from non-relevant, and generally adjust to a classroom learning environment. Many studies have found that inhibitory control ability is an important predictor of language and math skills in preschool and in later school years (21, 23, 25, 26). Thus, failure to inhibit appears to be an important reason for some children's decreased ability to learn and poor academic performance.

Inhibitory control is therefore an important executive control function to investigate in low-income children, who appear to perform more poorly on tests of general cognitive skills, particularly when exposure to poverty occurs in early childhood. We hypothesize that an impairment in inhibitory executive control functions may be one neural mechanism that mediates the influence of economic disadvantage on cognitive development.

Some preliminary research has suggested that economic disadvantage is associated with poorer executive functioning in children. A small ($N = 60$), cross-sectional study among African-American kindergarteners compared children of low socioeconomic status (SES), defined as income-to-need ratio less than 1.3,[2] parental occupation categorized as unskilled or technical, and parental education no greater than high school, with children of middle SES on a variety of neuropsychological tasks (27). The study found that SES was disproportionately associated with composite scores on tasks tapping the prefrontal executive function system and the left perisylvian language system. In particular, children of low SES performed significantly worse on the executive functioning tasks that require inhibition, such as correct no-gos on a Go/No-Go task and false alarm rates on other tasks. Interestingly though, after controlling for children's language abilities, SES no longer accounted for unique variance in executive function ability.

A follow-up study among 60 African-American children ages 10 through 13 examined sub-components of prefrontal executive functioning more specifically (28). In addition, the low SES participants had normal growth and no history of potentially confounding general medical conditions, neuropsychiatric illness, or neurologic insult. Compared with middle SES children, the low SES children were found to perform more poorly on the tasks tapping working memory and those tapping cognitive control. No SES differences were found on tasks tapping reward processing.

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[2] An income-to-need ratio is a measure that describes the depth of poverty. It is calculated by dividing a household's income before taxes by the corresponding federal poverty line (e.g., $21,203 for a family of 4). Thus a family with an income-to-need ratio of 1.0 is living at the poverty level, while a family with an income-to-need ratio of 0.5 is living on an income fifty percent below the poverty level, and a family with an income-to-need ratio of 1.5 has an income that is 50 percent above the poverty level. Please see the methods section for additional details.

A second follow-up study tested a larger sample (*N* = 150) of ethnically diverse first graders recruited from New York City public schools on a slightly different battery of neurocognitive tasks that also tapped sub-components of prefrontal executive functioning (29). This study used continuous income-to-need data, along with measures of parental education and occupation, to create a continuous SES index. Similarly to the previous studies, SES was found to be correlated with composite scores on tasks tapping working memory and cognitive control, but not with those tapping reward processing. Looking at performance on the individual executive function tasks, as opposed to the composite scores, SES accounted for the most variance in performance on a Stroop-like task and the NEPSY auditory attention and response set, which involves working memory, inhibition, and cognitive flexibility.

Another cross-sectional study of 249 children ages 5 to 7 examined performance on an Attention Network Test by SES (30). The task was designed to separately examine alerting attention, orienting attention, and executive attention. Executive attention is comparable to executive functioning, involving planning, initiating, anticipating consequences, selecting among competing demands, and monitoring and modifying behavior. SES was found to have the largest effect on the executive attention measures.

In addition to these behavioral studies, one study has used electrophysiology to directly measure prefrontal neural activity during an executive function task (31). The task involved detecting target stimuli out of a series of standard stimuli, and it also included some novelty stimuli. Continuous electroencephalogram (EEG) monitoring was performed on 13 low SES children and 13 high SES children ages 8 to 11. The study examined three event-related potentials (ERPs) previously found to be decreased among patients with lateral PFC damage, the extrastriate P1 and N1 ERPs and the novelty N2 ERP. The researchers found that these prefrontal dependent ERPs were reduced in low SES children compared with high SES children, while no difference was observed in the other non-PFC ERPs that were examined.

The current investigation aims to further explore this association between poverty and poor executive functioning using longitudinal data, with careful attention to inhibitory control abilities. Data from the ongoing Yale Young Children's Learning Study (YCLS) is used to examine how poverty affects young children's performance on a picture AX Continuous Performance Task (AX-CPT), a neurocognitive task that requires inhibitory control.

## Specific Hypothesis and Aims

We hypothesize that children living in more economically disadvantaged families will have delayed development of their inhibitory control abilities and will have altered developmental trajectories with increasing developmental lag compared to children living in more economically advantaged families. First, this study aims to model these developmental trajectories for children ages 5 through 8, using performance data from a picture AX-CPT that requires inhibition. Second, this study aims to examine how gender and economic deprivation may influence these neurocognitive trajectories.

## Methods

### *Participants*

The participants in this study were normally developing children enrolled in the Yale YCLS study, an ongoing longitudinal study of young children's learning and development of executive control functioning. This paper examines a cohort of 125 children enrolled in the larger study who were 5 years old in 2004, 2005, or 2006. Data was extracted in 2008, therefore all subjects had the opportunity to be followed yearly for either three or four years.

Participants aged 4 through 8 years were recruiting into the YCLS study beginning in 2005 through several methods. Some children were recruited through letters to families that were part of two birth cohorts enrolled previously by Drs. Michael Bracken and Kathleen Belanger (Yale School of Public Health, Division of Perinatal Epidemiology) for studies of maternal caffeine intake during pregnancy and maternal asthma. The mothers were recruited before the 24$^{th}$ week of gestation from 56 private obstetrical practices and 15 hospital-based clinics in Bridgeport, Danbury, Hartford, and New Haven, Connecticut. Additional children were recruited to the YCLS study through advertising around New Haven County, by word-of-mouth, and from other studies at the Yale Child Study Center. Interested families were then screened over the telephone to determine eligibility. Exclusion criteria were: perinatal history of prematurity with ICU admission for two weeks or more and/or perinatal complications with associated neurological sequelae, documented history (from parent report or medical record) of parental use of illicit drugs during pregnancy, history of neurological conditions such as cerebral palsy or seizure disorders, history of head trauma with loss of consciousness in the year prior to enrollment, history of foster placement, or history of more than six months of separation from biological parent(s). Only two children were excluded due to symptoms of autism. All enrolled children spoke English and had visual acuity greater than or equal to 20/40 with correction. Written consent was obtained from all parents prior to participation.

As shown in Table 1, of the 125 total participants, 55.2 percent ($N$ = 69) of the children were male and 44.8 percent ($N$ = 56) of the children were female. An ethnicity was reported by 97.6 percent ($N$ = 122) of the participants. Sixty-four percent of children were Caucasian, 19.2 percent were African American, 8.8 percent were Hispanic, and 5.6 percent chose "other." Slightly more Caucasian children were male ($N$ = 47, 58.8 percent of Caucasians) compared with female ($N$ = 33, 41.2 percent of Caucasians). The other ethnic groups had similar numbers of males and females. The median income-to-need ratio of the 5-year-old children's families was 4.06 ($N$ = 74, mean = 4.49, $SD$ = 3.11, range = 0.23 to 19.22). The mean age of the children when they performed the AX-CPT at their 5-year-old visit was 5.38 ($N$ = 108, $SD$ = 0.29, range = 5.00 to 5.92), at their 6-year-old visit was 6.18 ($N$ = 98, $SD$ = 0.17, range = 6.00 to 6.75), at their 7-year-old visit was 7.17 ($N$ = 77, $SD$ = 0.16, range = 7.00 to 7.83), and at their 8-year-old visit was 8.14 ($N$ = 45, $SD$ = 0.12, range = 8.00 – 8.75).

**Table 1: Participant Demographics**

| | | |
|---|---|---|
| Total Participants | | $N$ = 125 |
| Gender | Percent | $N$ |
| Male | 55.2 | 69 |
| Female | 44.8 | 56 |
| Ethnicity | Percent | $N$ |
| Caucasian | 64.0 | 80 |
| African American | 19.2 | 24 |
| Hispanic | 8.8 | 11 |
| Other | 5.6 | 7 |
| No Response | 2.4 | 3 |
| Age Category | Mean age in years (*SD*, range) | $N$ |
| 5 year olds | 5.38 (0.29, 5.00 – 5.92) | 108 |
| 6 year olds | 6.18 (0.17, 6.00 – 6.75) | 98 |
| 7 year olds | 7.17 (0.16, 7.00 – 7.83) | 77 |
| 8 year olds | 8.14 (0.12, 8.00 – 8.75) | 45 |
| Income-to-need ratio | Median (*M*, *SD*, range) | $N$ |
| All participants | 4.06 (4.49, 3.11, 0.23 – 19.22) | 74 |
| "Low" income-to-need < 2 | 0.69 (0.91, 0.59, 0.23 – 1.80) | 12 |
| "Adequate" income-to-need > 2 | 4.40 (5.18, 2.92, 2.12 – 19.22) | 62 |

*Visits*

Children in the YCLS study visited the Yale Child Study Center two times per year. At each visit the children completed five different neuropsychological tasks for a total of ten different tasks each year. Testing occurred in a quiet room with a trained tester. Parents could choose to be present in the testing room or to watch via video from a nearby room. During the first session, the children completed an attention task, a self-ordered pointing task, the Kaufman Brief Intelligence Test (K-BIT) (32), the NEPSY (33) (4-year-olds) or the Wide Range Assessment of Memory and Learning (WRAML) (34) (children 5 years and older), and a serial learning task. During the second session, they completed Stroop tasks, a Corsi-Blocks test, a picture AX-CPT, a color task, and a reversal learning task. The order of the tasks was varied each day to control for possible performance effects due to session length. In addition, each child's height, weight, and visual acuity were measured annually.

While the child was completing the neuropsychological tasks, the parent who was present filled out questionnaires covering demographic information including parental occupation and education, family learning history, child medical history, family size, and household composition. Parents also answered questions about their child's personality, behavior, and psychopathology by completing the Child Behavior Checklist (CBCL) (1.5-5 year version (35) for 4- and 5-year-olds and 6-18 year version (36) for children 6 years and older), the Behavioral Assessment System for Children (BASC) (37), the Swanson, Nolan, and Pelham Questionnaire (SNAP-IV) (38) disruptive behavior section, and the Early Childhood Inventory (ECI-4) (39) (for children ages 4 and 5) or the Child Symptom Inventory (CSI-4) (40) (for children ages 5 to 8). In addition, the parent completed the Brief Symptom Inventory 18 (BSI-18) (41) and the Pearlin Mastery Scale (42) to provide information about parental psychological distress and feelings of control, the Confusion, Hubbub, and Order Scale (CHAOS) (43) to approximate the level of commotion in the child's home, and a family routines questionnaire aimed at assessing family values. Between visits, parents were asked to fill out three questionnaires at home: the Parenting Stress Inventory and Life Events (PSI) (44), which assesses the magnitude of stress in the parent-child system, the Parent Child Relationship Inventory (PCRI) (45), which assesses parents' attitudes toward parenting and their children, and a questionnaire describing household income, expenses, and wealth. They were also asked to have another adult who knows the child well fill out the BASC or CBCL.

Families were compensated $30 for each visit and $10 for providing their own transportation. If they completed and returned the four take-home questionnaires, they could also earn up to $20 ($5 per questionnaire). Thus each family could earn up to $100 per year for participation. Additionally, the child received a toy at each visit.

*Measurement of Poverty*

The official measurement of poverty in the United States is based on a set of income standards developed in the 1960s. They were originally developed on the assumption that an average family spent one third of its income on food. Thus the cost of a minimum nutritionally adequate food plan was multiplied by three to create the poverty threshold (46). Currently, these poverty thresholds are adjusted for family size and age of members and are updated annually for inflation using the Consumer Price Index. In 2007 the weighted average poverty threshold for a family of four was $21,203 (1). If a family's total income is less than that family's threshold, then that family and every individual in it is considered in poverty. This approach uses monetary income before taxes from employment, unemployment compensation, workers' compensation, Social Security, Supplemental Security Income, public assistance, veterans' payments, survivor benefits, pension or retirement income, interest, dividends, rents, royalties, income from estates, trusts, educational assistance, alimony, child support, assistance from outside the household, and other miscellaneous sources (e.g., foster care payments) (47). It does not include capital gains or non-cash benefits such as food stamps, Medicaid, or public housing. While the poverty thresholds allow categorization of people as "in poverty" or "not in poverty," an income-to-need ratio is a measure that allows examination of the depth of poverty. It is calculated by dividing each household's income before taxes by its corresponding federal poverty threshold (1). Thus a family with an income-to-need ratio of 1.0 is living at the poverty level, while a family with an income-to-need ratio of 0.5 is living on an income fifty percent below the poverty level, and a family with an income-to-need ratio of 1.5 has an income that is 50 percent above the poverty level.

Although poverty rates are most frequently reported using these official poverty thresholds, researchers must be cognizant that this approach is subject to many criticisms as outlined in a report by the National Academy of Sciences (48).

These thresholds do not vary geographically to take into account the different costs of living and housing across the country. They may underestimate the resources of some families by not accounting for capital gains, food stamps, and housing subsidies. However, they may overestimate the resources of other families by not accounting for necessary expenditures such as taxes, healthcare expenses, childcare expenses, and child support payments.

Despite these criticisms, the federal poverty thresholds continue to be used by the United States Census Bureau for calculating federal poverty rates and by most academic studies examining poverty, and this study therefore uses the same concept for its measurement of poverty. Each year parents in the YCLS study were asked to report all income per month, including income from employment before taxes, child support and foster care payments, interest, investments, pensions, help from friends and family, and other. They were also asked to report monthly income from public programs including food stamps, housing subsidies, Temporary Assistance for Needy Families (TANF), childcare subsidies, Social Security, Supplemental Security Income, unemployment, workers' compensation, and any other public sources. Income data was collected in a continuous form. Number of family members was also reported, and this number was used to select the appropriate poverty guideline. The poverty guidelines are nearly identical to the poverty thresholds, but simplified for use by the Department of Health and Human Services in establishing aid program eligibility (49). These guidelines are often loosely referred to as the "federal poverty line." For this manuscript, income-to-need ratios were constructed by dividing each household's total reported income from employment by the federal poverty guideline corresponding to the appropriate year and participant family size.

*Measurement of Inhibitory Control*

Inhibitory control was measured using a continuous performance task (CPT) (50). A picture AX-CPT task was programmed and run in the E-prime application software package (51). Children sat a comfortable distance in front of a 9 by 12 inch computer screen and kept one hand resting above a single red button that was on the table in front of them. They were then presented with a series of colorful pictures chosen to be familiar to young children (e.g., flower, frog, bird). Each picture appeared in the middle of the computer screen for one second, with an inter-stimulus interval of 700 milliseconds. The children were instructed to press the button when and only when they saw a bunny (A) followed by an apple (X). If the child responded correctly, the apple would explode, providing an immediate visual and auditory reward designed to further motivate the child. For the first 80 stimuli, 80 percent of the time that either a bunny or an apple is seen, it is paired with the other in the correct order to create an expectation that usually the apple immediately follows the bunny.

To familiarize children with the task, instructions were first given orally using a booklet containing pictures that illustrated the scenarios the child would encounter in the task. Before continuing, the children had to answer a series of questions about the task to verify understanding of the rules. Directions were then repeated interactively using E-prime. The program demonstrated to the children that simply pressing the button after an apple that was not preceded by a bunny was an incorrect response and the apple would not explode. Each child then completed 21 practice trials and 285 test trials. The task took between 5 and 8 minutes to complete, depending on the participant's response speed.

The AX-CPT task requires that a child remember a rule (press a button when and only when an apple comes after a bunny), continually update his or her working memory of what has just been seen, selectively attend to relevant stimuli while inhibiting attention to distractors, and inhibit pressing the response button to incorrect stimuli. Because target (bunny-apple) trials occur 80 percent of the time for the first 80 stimuli, children become biased that an apple will usually follow a bunny. When an apple is presented not preceded by a bunny (BX), they must therefore inhibit a prepotent response to press the button to the apple. Similarly, when a bunny cue is not followed by an apple (AY), children must inhibit a prepotent response to press the button to the stimulus that does follow the bunny.

AX-CPT type tasks are thought to rely heavily on PFC function. Children with attention deficit/hyperactivity disorder (ADHD), who are thought to have deficits in PFC function, demonstrate poorer performance on these types of tasks (52, 53). Similarly, patients with schizophrenia are thought to have PFC dysfunction, and they also show deficits on AX-CPT tasks (53). Moreover, in neuroimaging studies with adult patients, similar AX-CPT type tasks have been shown to consistently activate dorsolateral PFC (53, 54).

In this study, responses on the AX-CPT are classified into the following categories: hits (correct identification of a bunny-apple pair, AX), misses (errors of omission, not pressing the button in the presence of a bunny-apple pair), and false alarms (errors of commission, pressing the button to a stimulus other than a bunny-apple pair). False alarms are further divided into four subtypes: pressing the button to an apple not preceded by a bunny [BX], to a bunny alone [A], to a non-apple image following a bunny [AY], or to a random image [BY].

Thus, from the AX-CPT performance data, three outcome variables can be examined, each measuring different aspects of executive control functioning. Overall accuracy is a broad measure of selective attention, working memory, and inhibitory control. Overall accuracy is best assessed with a net percent score. Net percent scores are calculated by subtracting the percentage of errors of commission (false alarms) from the percentage of hits (55, 56). This method eliminates the chance of a child getting a high score by simply pressing the button for every stimulus presented. Moreover, it minimizes bias due to children's different strategies as children are not rewarded more for guessing than for omitting. The second outcome variable is number of errors of omission. Errors of omission most closely reflect a child's ability to sustain attention. Finally, the third outcome variable is number of false alarms, or errors of commission, and this is the outcome examined in the current study. False alarms most closely reflect a child's inhibitory control and impulsivity. Thus children with more errors, those who failed to inhibit pressing the button to incorrect stimuli, are considered to have poorer inhibitory control and greater impulsivity. In this study, we define inhibitory control errors as pressing the button to an apple not preceded by a bunny [BX], to a bunny alone [A], or to a non-apple image following a bunny [AY].

*Analytic Approach*

For the current investigation, latent growth curve modeling (LGM) was used to model trajectories for the development of inhibitory control. Specifically, EQS 6.1 (57) was used to examine the growth trajectory of children's inhibitory control from 5 to 8 years of age. LGM analyses require that several conditions be met. For example, measurements for each individual must be taken a minimum of three times, with additional measurements typically increasing the precision of parameter estimates. Additionally, it is also best for the spacing of measurements to be equivalent for all participants (58, 59). In the current study, either three or four measurements of inhibitory control were obtained. Furthermore, measurements, beginning when children were 5 years of age, were obtained at approximately one year intervals (age category means = 5.38, 6.18, 7.17, and 8.14 years, respectively).

When LGM is performed, an initial growth model is fit to repeated measures for each individual, which results in the ability to obtain intercept and slope factors, along with factor residuals, which represent deviations from the average intercept and slope (58, 60). If residuals are statistically significant, then the data indicate that interindividual changes over time are present. This suggests that additional analyses should be conducted to examine the potential effect of various factors (predictors) on the growth trajectories of inhibitory control. Gender and income-to-need are examined as predictors in the current investigation. When predictors are incorporated into the LGM model, residual terms associated with the slopes and intercepts represent the degree of interindividual change remaining after accounting for the predictors. Furthermore, examination of the parameter estimates for the predictor variables indicates whether a given predictor accounts for interindividual differences in the model (58-60).

An advantage of the LGM technique is the ability to impute missing data, a problem that is more common in longitudinal studies due to attrition. Imputation involves placing estimated values into the data set in the location of the missing values. Estimates are created based on all of the participant's non-missing values, the group mean values, the values for similar participants (pattern matching), and the values of all other variables in the LGM model. For this study, data imputation was performed in the LGM analysis for children with missing scores on the AX-CPT and for children with missing income-to-need ratios at age 5.

In the present study, the following robust fit indices were used to evaluate the fit of the initial linear LGM of inhibitory control as well as the LGM with child gender and income-to-need as predictors of individual differences in the intercept and slope of inhibitory control: chi-square goodness of fit index, comparative fit index (CFI), Akaike Information Criterion (AIC), and the root mean square error of approximation (RMSEA). For the chi-square, increased model complexity as well as a large sample size can render this value statistically significant. In general, a larger chi-square with a large number of degrees of freedom is not considered to reflect poor model fit. For the CFI, values above .90 suggest good to excellent fit. For the RMSEA, excellent fit is indicated by values between .00 and .05 with good fit indicated by values between .05 and .09. Finally, lower values of the AIC are suggestive of better model fit than relatively high values, although, no specific guidelines for the AIC have been provided (see (61-66) for complete descriptions of these fit indices).

## Results

As shown in Table 2, on average, 5-year-old children made 19.86 inhibitory control errors on the picture AX-CPT. The mean number of inhibitory control errors for 6-year-olds was 9.36, for 7-year-olds it was 7.55, and for 8-year-olds it was 4.76. On average, girls made fewer inhibitory control errors than boys at all ages. At all ages, there were children who made no inhibitory control errors, resulting in large ranges. However by age 8, there was much less variability in the number of errors (SD = 5.9) compared with age 5 (SD = 20.9).

**Table 2: Descriptive Statistics for Inhibitory Control Errors on the AX-CPT**

| | Mean number of IC errors (% of possible IC errors) | *SD* | Range | *N* |
|---|---|---|---|---|
| Age 5 | | | | |
| Total | 19.86 (12.41%) | 20.9 | 0 – 97 | 108 |
| Male | 23.47 (14.67%) | 22.3 | 0 – 97 | 55 |
| Female | 16.11 (10.07%) | 18.8 | 0 – 83 | 53 |
| Age 6 | | | | |
| Total | 9.36 (5.85%) | 14.5 | 0 – 68 | 98 |
| Male | 12.50 (7.81%) | 18.0 | 0 – 68 | 54 |
| Female | 5.50 (3.44%) | 7.1 | 0 – 29 | 44 |
| Age 7 | | | | |
| Total | 7.55 (4.72%) | 11.3 | 0 – 75 | 77 |
| Male | 9.15 (5.72%) | 13.6 | 0 – 75 | 40 |
| Female | 5.81 (3.63%) | 8.0 | 0 – 30 | 37 |
| Age 8 | | | | |
| Total | 4.76 (2.98%) | 5.9 | 0 – 22 | 45 |
| Male | 6.90 (4.31%) | 7.1 | 1 – 22 | 24 |
| Female | 2.88 (1.80%) | 3.7 | 0 – 15 | 21 |

The initial linear LGM of inhibitory control fit the data well, robust $\chi^2$ (5) = 10.16, $p$ = .07, *CFI* = .96, *AIC* = .16, and *RMSEA* = .08 (90% CI: .00 - .18). This model indicated that the intercept and slope of inhibitory control were significantly different from 0, $z$ = 35.51, $p$ < .01 and $z$ = -11.39, $p$ < .01. Consistent with developmental expectations, the slope is declining, on average, over time, which indicates that as participants are getting older, they are making progressively fewer inhibitory control errors over time. Significant interindividual difference were also present, as indicated by significant residuals associated with the intercept and slope factors, $z$ = 6.06, $p$ < .05 and $z$ = 7.98, $p$ < .01, respectively. Finally, the covariance between the slope and intercept factors was significant, $z$ = -5.19, $p$ < .01, indicating that on average, those participants who were initially committing more inhibitory control errors improved faster over time relative to participants who initially made fewer inhibitory control errors during performance on the task. Figure 1 contains standardized coefficients associated with the initial linear model. Figure 2 graphically shows the modeled individual trajectories of inhibitory control errors from ages 5 to 8 for all participants. (Note that Figure 2 and all subsequent figures incorporate missing data imputed by the LGM software.) For clarity, participants were divided into octiles based on baseline AX-CPT performance at age 5, and Figure 3 shows these eight trajectories of inhibitory control errors. Figure 4 shows the mean number of inhibitory control errors made by participants in each age group. Note that the means reported in Figure 4 are slightly different from those reported in Table 2 because Figure 4 incorporates imputed data from the LGM model.

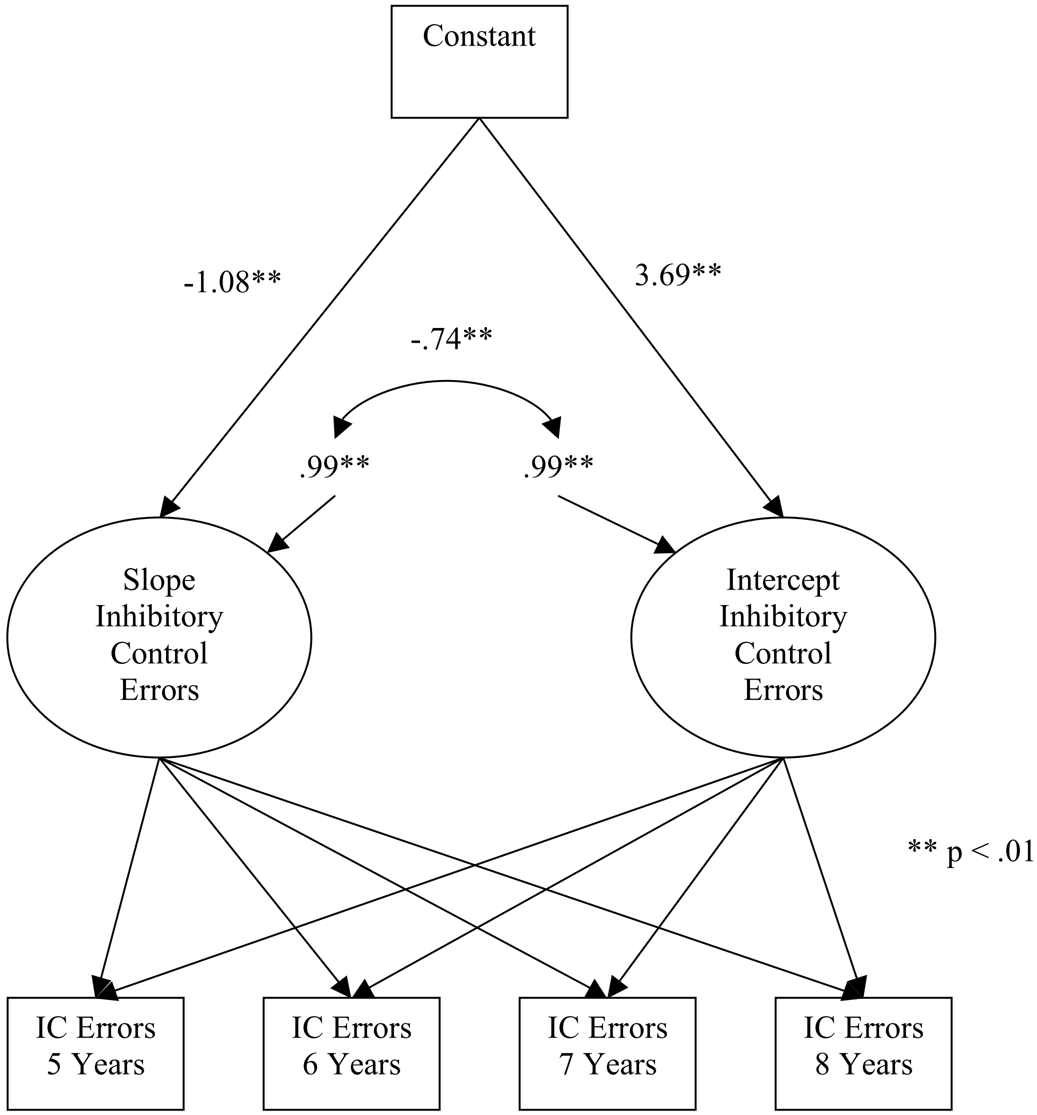



**Fig. 1. Linear LGM of Inhibitory Control Errors.** Single headed arrows represent the impact of one variable on another, double headed arrows represent covariance between variables. The coefficient -1.08 represents the slope (rate of change in IC ability) and the coefficient 3.69 represents the intercept (age 5 starting point on growth curve) of the LGM model. The two coefficients .99 represent the residuals (individual differences from the average) for slope and intercept. The coefficient -.74 represents the covariance between slope and intercept residuals. IC, inhibitory control.

**Fig. 2. Individual Trajectories of Inhibitory Control Errors from Age 5 to 8 Years**

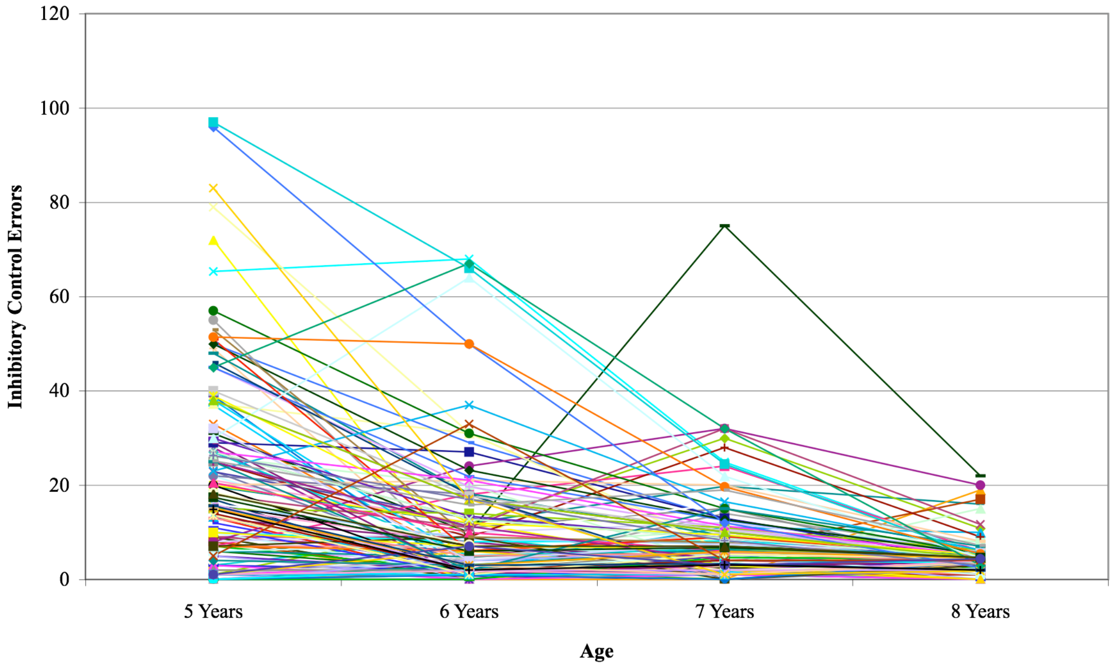



**Fig. 3. Trajectories of Inhibitory Control Errors from 5 to 8 Years Grouped by Octiles Based on Performance at Age 5 Years**

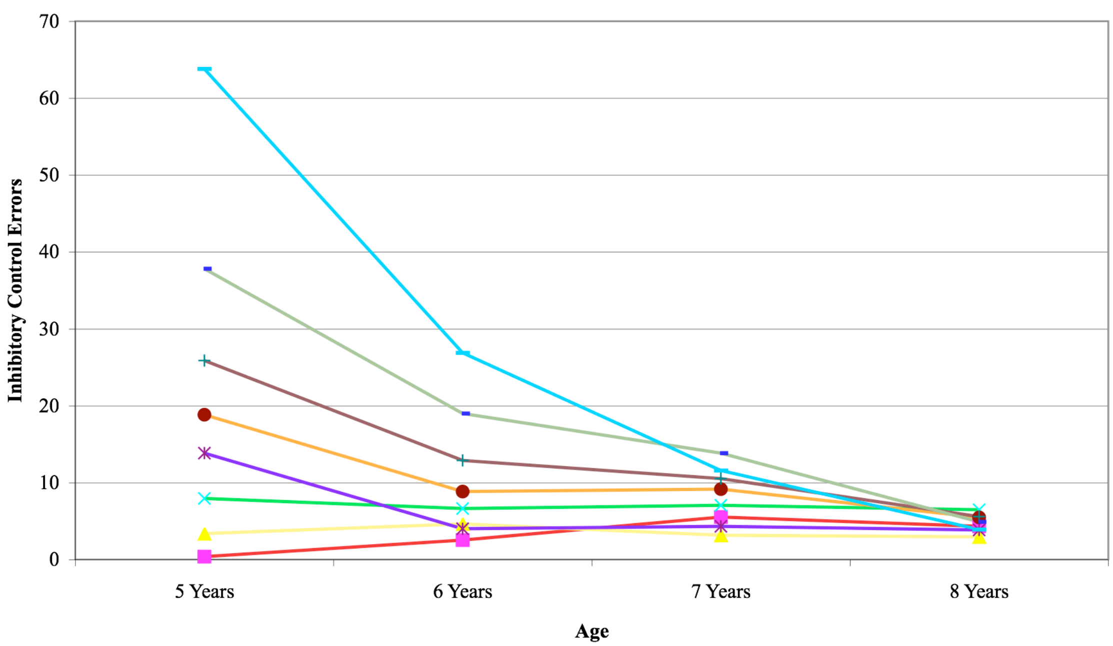


Fig. 4. Trajectory of Mean Inhibitory Control Errors from 5 to 8 Years of Age

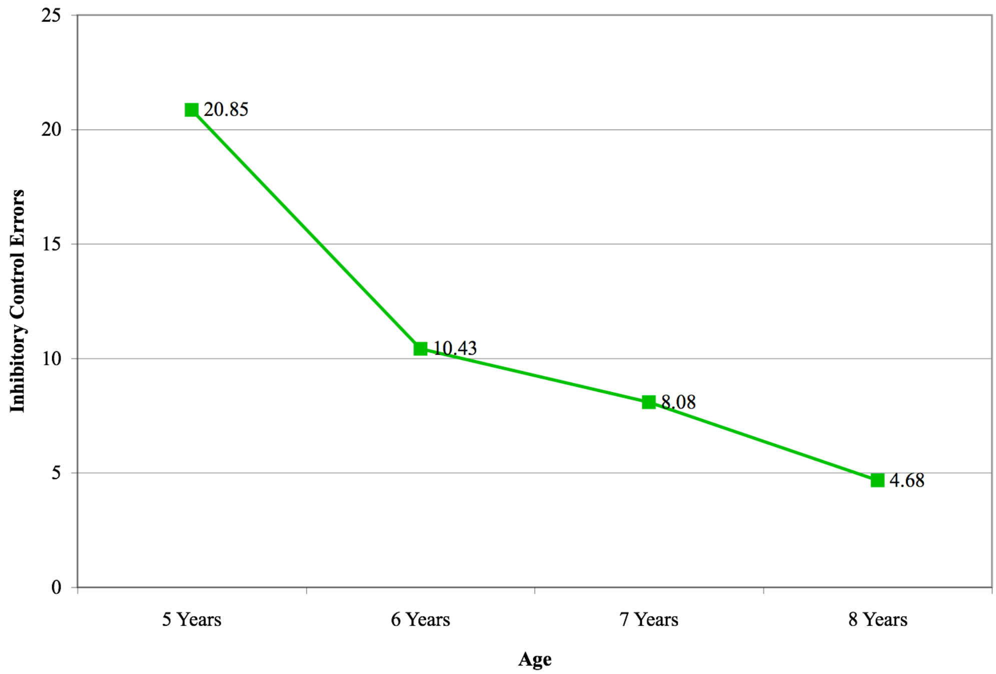
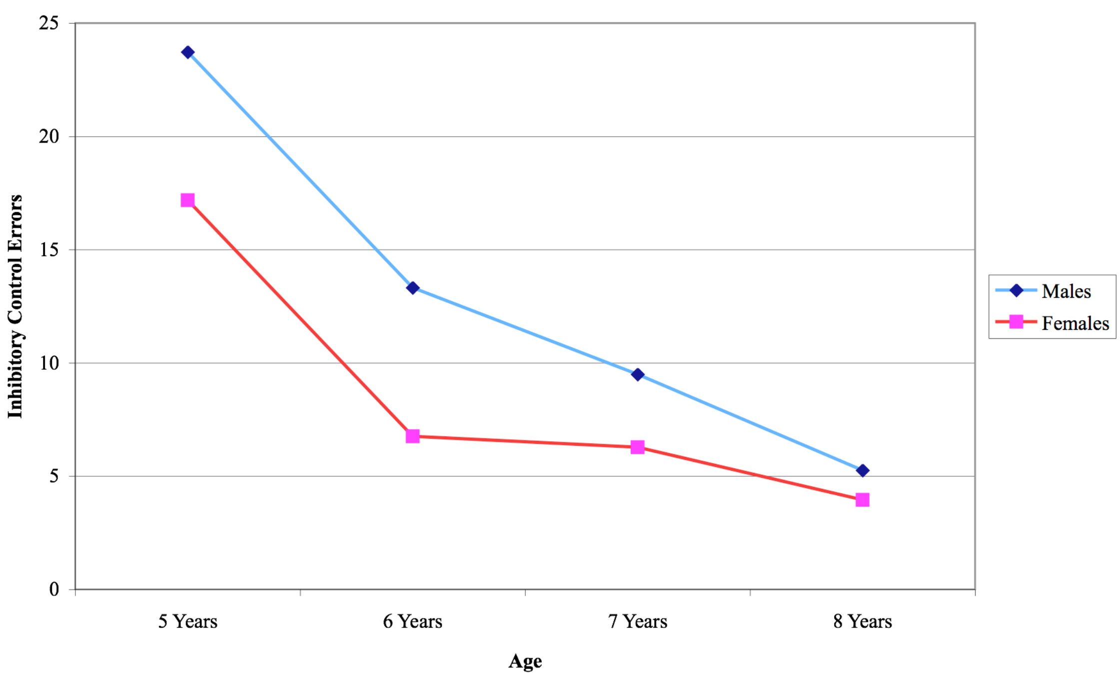



Fig. 5. Trajectories of Inhibitory Control Errors by Gender



The final linear LGM model included gender and income-to-need ratio as predictors of interindividual differences in the intercept and slope of inhibitory control. Two significant and noteworthy effects emerged based on findings in the predictor model. Male children made more inhibitory control errors initially (i.e., intercept) than female children, $z = -2.84$, $p < .01$. The different trajectories of inhibitory control for boys and girls are shown in Figure 5. After controlling for child gender, children coming from families with higher income-to-need ratios (i.e., more advantaged families) made fewer errors at 5 years of age (i.e., intercept) relative to children coming from families with lower income-to-need ratios (i.e., more disadvantaged families), $z = -2.16$, $p < .05$. Figure 6 contains standardized coefficients associated with the final LGM model. Overall, the predictor model, with gender and income-to-need accounting for individual differences in the intercept of inhibitory control, was an excellent fit to the data, $\chi^2$ (9) = 15.13, $p = .09$, $CFI = .98$, $AIC = -2.87$, and $RMSEA = .04$ (90% CI: .00 - .11). Together, gender and income-to-need ratio accounted for 12 percent of the variance in individual differences for intercept. Neither gender, $z = -.02$, $p > .05$, nor income-to-need, $z = 0.72$, $p > .05$, accounted for individual differences in the rate of change (i.e., slope) of inhibitory control from 5 to 8 years of age.

Figure 7 shows the trajectories of inhibitory control with participants divided into octiles based on income-to-need ratio at age 5. An exploratory analysis was also conducted comparing performance of children with “low” income-to-need ratios, defined as less than 2.0, to children with “adequate” income-to-need ratios, defined as greater than 2.0. We chose 200 percent of the federal poverty line because it is a cut-off commonly used to determine assistance program eligibility. Figure 8 shows the trajectories of inhibitory control for the “low” and “adequate” income-to-need groups.

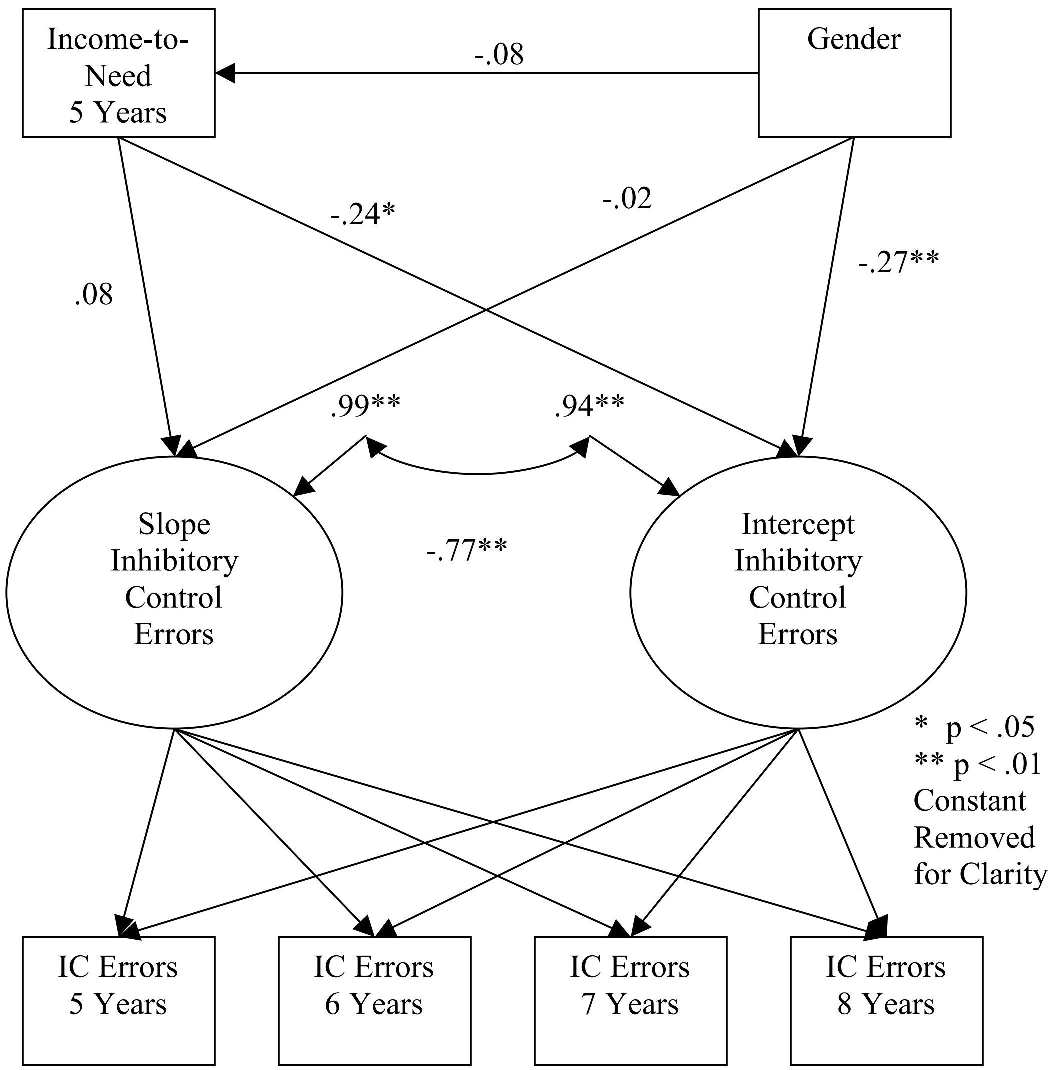



**Fig. 6. Linear LGM of Inhibitory Control Errors with Gender and Income to Need Ratio as Predictors.** The model shows that gender and income-to-need ratio at age 5 partially account for interindividual differences (residuals) in the intercept for inhibitory control errors. Neither gender nor income-to-need at age 5 accounted for individual differences in the rate of change (i.e., slope) of inhibitory control ability from 5 to 8 years of age. IC, inhibitory control.

**Fig. 7. Trajectories of Inhibitory Control Development from 5 to 8 Years Grouped by Octiles Based on Income-to-Need Ratio at Age 5**

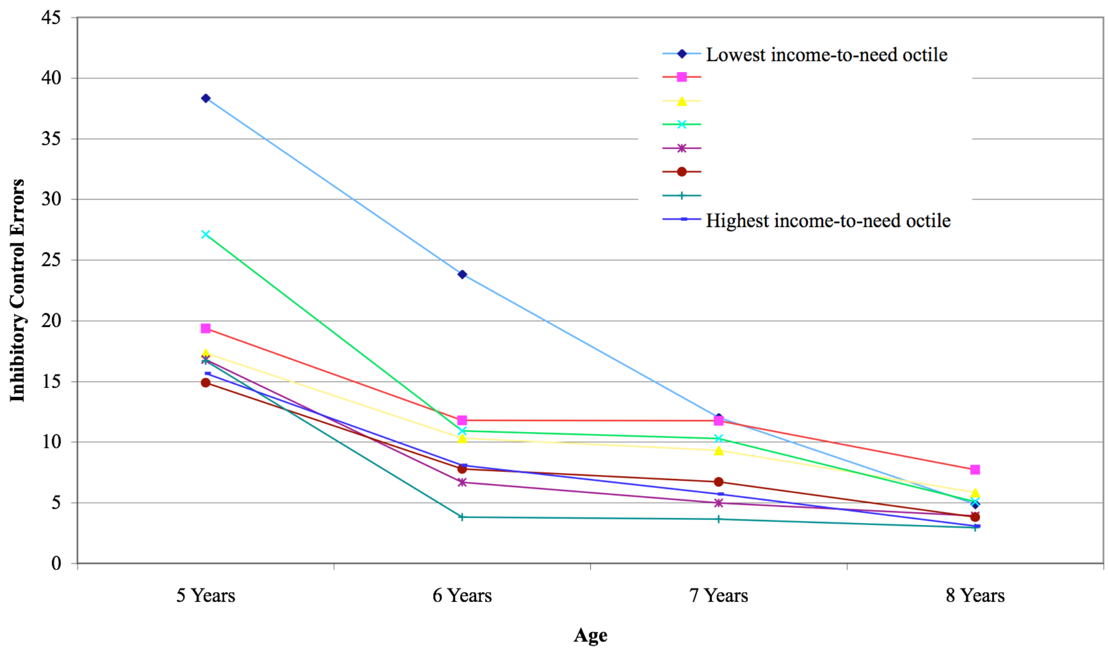
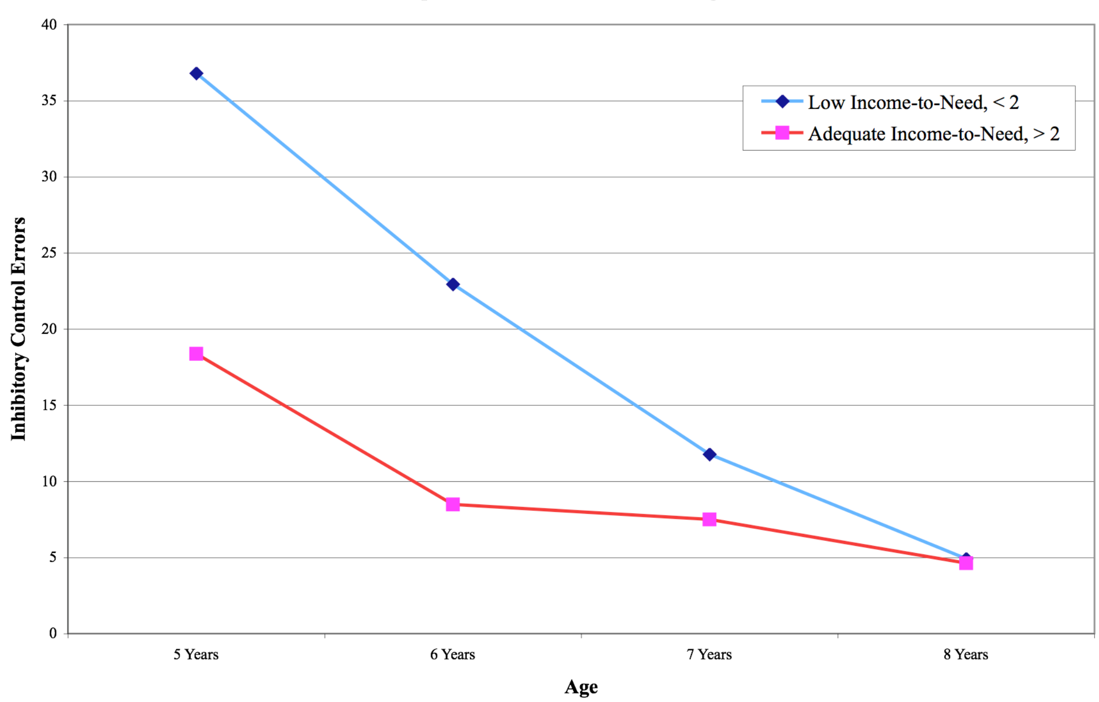



**Fig. 8. Trajectories of Inhibitory Control Development from 5 to 8 Years Grouped Based on Low Versus Adequate Income-to-Need Ratios at Age 5**



## Discussion

This study builds on previous research from multiple disciplines. Research from the fields of child development, sociology, and economics has consistently demonstrated broad negative effects of poverty on children's cognitive development. Neurobiology research has clearly shown that experience can affect the biology of brain development and that PFC has a prolonged period of postnatal development, making it especially susceptible to environmental influences like poverty. Researchers in the field of cognitive neuroscience have used imaging studies to localize executive functioning to the PFC, have parsed out the construct of executive function and its sub-components, and have created tools like the AX-CPT that selectively assess sub-components like inhibitory control. Meanwhile, research in developmental cognitive neuroscience has shown that inhibitory control emerges gradually from preschool to early school age, paralleling anatomic and biochemical maturational changes in PFC. Lastly, research in the field of child development has shown that failure to inhibit appears to be an important reason for children's difficulty learning and poor academic performance. The results of all this multidisciplinary research helped to generate the broad hypothesis of this study: that living in poverty may affect development of PFC and consequently the development of inhibitory control, and that poor inhibitory control may lead to poorer academic performance and negative cognitive outcomes. Thus, the current investigation specifically hypothesized that children living in more economically disadvantaged families would have delayed development of their inhibitory control abilities as well as altered developmental trajectories compared to children living in more economically advantaged families. Commission errors (false alarms) on a picture AX-CPT were used as the measure of poor inhibitory control.

To our knowledge, this is the first published study to longitudinally examine the potential influence of growing up in poverty on the emergence and development of young children's inhibitory control abilities. The results demonstrate two important findings. First, consistent with developmental expectations, we found that as children get older they make progressively fewer inhibitory control errors. This supports previous work that has demonstrated the gradual emergence of inhibitory control abilities from preschool to early school age (18, 24). In addition, significant interindividual differences in both the slope and intercept factors were found, indicating the need to examine potential predictors of these differences. Secondly, the current study found that child gender and income-to-need ratio at age 5 account for significant interindividual differences (explaining 12 percent of the variance) in 5-year-olds' inhibitory control ability, even after controlling for the other predictor. At age 5, male children and children from more economically deprived families had more inhibitory control errors. This result is consistent with our hypothesis that more economically disadvantaged children would have delayed development of their inhibitory control abilities compared to children from more advantaged families. However, an unexpected finding from this study was that child gender and income-to-need ratio at age 5 did not account for significant interindividual differences in trajectory slope. We did not find increasing developmental lag for inhibitory control ability as we had hypothesized. Thus, while family resources at age 5 appear to affect children's inhibitory control ability at age 5, resources do not appear to independently affect children's rate of development of inhibitory control from then on. In other words, economically disadvantaged children already demonstrate poorer inhibitory control by age 5, but after controlling for this difference in baseline ability, they improve at the same rates as their more advantaged peers. This unexpected result suggests that the impact of poverty on PFC development and subsequent development of inhibitory control occurs early (before age 5), putting children on a particular trajectory based on this early exposure to poverty.

A possible explanation for this result is that our study may have been limited in its ability to detect an impact of poverty on the rate of inhibitory control development. One reason is that we began to observe a ceiling effect for the task among 7- and 8-year-olds. Therefore the task, though appropriately difficult for the younger participants, was too easy for the oldest children. This ceiling effect is problematic because there is little performance variability among the 7- and 8-year-olds, making it hard to distinguish between levels of inhibitory control ability in the oldest age groups. The ceiling effect therefore limits the possibility of observing an effect of poverty that could be present, had the task been more difficult. However, designing a task that is developmentally appropriate for all children ages 5 to 8 is a challenge, as a harder task would have been too hard for the youngest children. Future studies may need to use a harder variant of the inhibitory control task to study the oldest children, while having the middle-aged children perform both variants for comparison.

A second reason our study may have had limited ability to detect an impact of poverty on the rate of inhibitory control development is that our sample did not have a high percentage of children living in poverty. This is apparent in that the median income-to-need ratio at age 5 was 4.06. Moreover, only 16% of those who reported income data had income-to-need ratios under 2.0 (200% of the federal poverty line), a cut-off commonly used to determine assistance program eligibility. Unfortunately, while the YCLS study has recruited children living under the poverty line more successfully in recent years, many of those children have not yet had the chance to have three visits, and were therefore not included in the analyses in this manuscript. Not having a high proportion of children living in poverty could be especially problematic because some research has shown that income may have non-linear effects on cognitive outcomes (5, 11, 67). In other words, the impact of income on inhibitory control may be much larger among low-income children than among higher income children, consistent with the view that "reducing poverty is associated with improved outcomes for children, whereas increasing affluence is not" (68). If income does have non-linear effects, we could postulate that there may be a theoretical threshold where income is adequate enough to protect a child from the effects of poverty, allowing the child to more fully reach his or her genetic potential for inhibitory control. Above this threshold, the family may have enough resources to provide for a child's nutritional and medical care needs, to move to a more advantaged neighborhood with less violence and better schools, to purchase stimulating learning materials, or to avoid high levels of family stress. To consider this concept further, we conducted an exploratory analysis comparing children with "low" income-to-need ratios (under 2.0) to children with "adequate" income-to-need ratios (greater than 2.0). The results, shown in Figure 8, lend support to the concept that the effect of income may be non-linear. Future research should further explore this hypothesis.

*Implications and Applications*

The findings from the current investigation provide important baseline data on the trajectories of young children's development of inhibitory control. This data will allow developmental investigators to take into account the effect of economic disadvantage on children's inhibitory control when studying populations that are disproportionately low-income.

Yet most importantly, a major goal of the current study was to investigate possible brain-based mechanisms through which poverty might affect cognitive outcomes. Understanding which component neurocognitive capacities are influenced by poverty may allow development of more targeted interventions to maximally improve cognitive outcomes among low-income children.

As discussed previously, several studies have found that inhibition is an important predictor of language and math skills in preschool and in later school years (21, 23, 25, 26). As a result, it is logical to try to design interventions to reinforce and improve children's inhibitory control. Several previous attempts have been made to implement interventions aimed at improving children's self-regulatory behaviors (21, 24, 69-71).

In one of these attempts, researchers designed and evaluated an intervention that involved training and practice on laboratory type tasks (24). This experimental study involved 49 children ages 3 to 5 who completed a Go/No-Go task and were classified as non-inhibitors because they failed to inhibit the inappropriate response more than 80 percent of the time. These children were randomized to one of three interventions: three sessions of training with explicit performance feedback on a Wisconsin Card Sort-type task and a Change-type task, three sessions of simple practice on the same Go/No-Go task, or no additional sessions at all (control group). On a re-test after the interventions, children in the training and practice groups were found to have significantly improved inhibitory control. The training group showed the greatest improvement, which was significantly greater than the improvement of the practice alone group.

A second study evaluated a five-day training intervention designed to improve executive attention, which is comparable to executive functioning, through the use of computer exercises (71). The participants, 49 4-year-olds and 24 6-year-olds, were randomly assigned to intervention or control groups. The children performed an Attention Network Test pre- and post-training. The study found that the trained children showed improved ability to resolve conflict on incongruent trials after the training, and this improvement was greater than that of the controls. The trained children also showed more mature patterns of brain activation on analysis of scalp ERPs.

The ADHD literature also provides some evidence that interventions can improve inhibitory control in impulsive children. In one study, the effect of an eight-week intervention to improve attention skills was investigated among children with ADHD who were between the ages of 7 and 11 (69). Seven children received an intervention designed to improve attention and executive function skills through tasks and games, and 7 children who were matched for age, sex, and medication status received a control intervention. Both interventions involved 30 minute, bi-weekly sessions in which each child was seen individually. The greatest improvements after the intervention were seen on tests of selective attention, such as the Stroop Day-Night Task. As selective attention involves selectively attending to relevant stimuli while ignoring and inhibiting responses to irrelevant stimuli, these children demonstrated improvements in inhibitory control.

A second type of intervention that has been studied among children with ADHD is teaching self-regulatory techniques. Several slightly different techniques have been studied, such as self-monitoring, in which a child learns to self-assess whether or not a behavior occurred and then self-record the result, self-monitoring with external reinforcement, and self-reinforcement, in which a child self-monitors and self-rewards for performing the target behavior. A meta-analysis of studies examined the efficacy of these “self-talk” interventions among children who were mainly between ages 7 and 12 (70). The meta-analysis found that these interventions can produce reductions in children’s inappropriate and disruptive behaviors and improvements in on-task behaviors. The average effect sizes for these behavioral changes were classified as large.

Although the interventions described in all of these studies have shown promise, they all involve intensive, one-on-one training in a specialized setting, which makes them both resource-intensive and expensive. Moreover, it is questionable whether the skills gained will generalize to other settings or demonstrate persistent, long-term effects. Another approach that has recently been studied is implementation of a school-based curriculum that promotes executive function abilities at the preschool age, thus better preparing children for school entry (21). Tools of the Mind is one such curriculum that involves 40 activities that promote all three components of executive functioning: inhibitory control, working memory, and cognitive flexibility. These activities involve self-regulatory talk, planned dramatic play, and aids to facilitate memory and attention. Strategies for supporting and training executive functioning are intertwined within most classroom activities such that teachers spend approximately 80 percent of each day promoting executive functioning skills. In a recent study in a low-income, urban school district, teachers were randomly assigned to teach the Tools of the Mind curriculum or a new, school district-designed balanced literacy curriculum, both of which taught the same academic content (21). A total of 147 preschool children were randomly assigned to classrooms teaching one of the two different curricula. After one or two years in the classroom, children's executive functioning skills were assessed on a Dots task and a Flanker task. Children who had been taught the Tools of the Mind curriculum performed significantly better on these neurocognitive tasks. In addition, performance on the task conditions that were most demanding of executive function skills correlated most strongly with performance on standard academic outcome measures, suggesting a significant academic benefit to strong executive function skills. The study concludes that Tools of the Mind is a low-cost intervention that improves executive functioning in preschoolers and can be implemented by teachers in standard classrooms without the need for specialists, computers, or additional one-on-one teaching time.

In summary, the results from the present study suggest that these types of interventions would be particularly useful among low-income children, who appear to have poorer inhibitory control at age five compared to higher income children. Because inhibitory abilities appear to predict future language and math skills, we postulate that these types of interventions may even help to narrow the gap in cognitive outcomes between poor and non-poor children. This conclusion would have important implications for early education programs. It suggests that these programs might have even better results if their curricula were tailored to teach and reinforce executive functions like inhibitory control.

### *Limitations*

As with any study, these conclusions have several limitations. Most importantly, despite the longitudinal design, this is only a correlational study, so no conclusions about causation can be made. However, a randomized, experimental design is not feasible for answering questions about the influence of poverty, so researchers must depend on well-designed correlational studies to test these hypotheses.

In addition, it is always possible that an unexamined variable could be confounding the results. This potential confounder would need to be associated with both poverty and poor inhibitory control at age 5 but not be in the mechanistic pathway. In the current study, many potential confounders were broadly addressed through the exclusion criteria. For example, while low birth weight might be associated with both poverty and poor inhibitory control at age 5, this sample is not a perinatally high-risk sample, as any child whose low birth weight required more than two weeks of care in the intensive care unit was excluded. Similarly, it is possible that either smoking during pregnancy or low parental education may be associated with both low income and poor inhibitory control at age 5. Future studies will need to assess whether these potential confounders are indeed related to inhibitory control, and if so, to control for them in the analyses.

Perhaps, it is not income but genetics that leads to poorer inhibitory control at age 5. For example, neurocognitive processes like inhibitory control, as well as cognitive outcome measures like IQ, may be genetically determined or “hard-wired,” suggesting that the described association is actually reversed and that poor inhibition and low IQ lead to reduced adult income. While there is no way to fully address this argument without genetic analysis, previous research has shown that measures of cognitive function like IQ are not determined purely by genes and can, in fact, be heavily influenced by environmental factors. This appears to be especially true among low SES children. For example, results from twin studies have demonstrated that for the poorest children, genes account for essentially none of the variability in IQ, while environment accounts for 60 percent. However, for affluent children, nearly all the variability in IQ is accounted for by genes (72). Similarly, data from adoption studies has shown that regardless of the SES of the biological parents, children adopted by high-SES parents score higher on IQ tests than children adopted by low-SES parents, implying an important effect of environment on IQ (73). Thus, while research still needs to examine the genetic versus environmental contributions to inhibitory control ability, it is unlikely that inhibitory control is entirely “hard-wired” and more likely that environment is an important determinant of inhibitory control ability, especially in low SES children.

There are also important limitations to consider related to the selection of the study population and the operational definitions of the dependent and independent variables in the current study. In terms of the study population, much of the recruitment was done by word-of-mouth, which creates the possibility for selection bias. For example, families previously connected to the Yale Child Study Center or families concerned about their child’s development may have been more likely to enroll. In addition, for many participants, we depended on parental self-report of illicit substance use during pregnancy to determine eligibility. We therefore cannot rule out the possibility of prenatal illicit drug use affecting brain development and development of inhibitory control in some study participants.

In measuring income, the independent variable, we relied on self-reported income data from parents, which creates the possibility of reporting bias. Parents may not accurately recall their income, may forget about smaller sources of income, or may feel a need to understate or overstate their resources. In addition, as discussed above, accurately measuring poverty is challenging, and the traditional measure we used likely underestimates how much income a family requires to meet its basic needs. Moreover, an income-to-need ratio does not capture how family members perceive their level of economic deprivation or how they feel about their own resources relative to those of other people around them. This “perceived poverty” or “relative poverty” may influence stress level, a potential pathway by which poverty may act on a child's development. Lastly, poverty is a dynamic state, and families often have frequent fluctuation of resources. This study asked parents to report income by month to make it easier for parents to recall the necessary information. Yearly income estimates were then made based on these reports. However, this technique may not accurately capture resources, as a family's income may differ drastically from month to month. Similarly, our models incorporate only the income-to-need ratio of each child at age 5, yet a family's resources certainly may change significantly from year to year.

To measure inhibitory control, the dependent variable, this study used a picture AX-CPT task. As discussed above, AX-CPT type tasks are thought to require inhibition to prevent errors of commission and to rely heavily on PFC. Nevertheless, the study has some limitations related to the AX-CPT task. First, only one inhibitory control task was examined in this study, which limits the conclusions. Performance data from other tasks that require inhibition would lend further support to the results. Additionally, a behavioral task is only an indirect measure of brain function. Because all behavioral tasks engage multiple brain systems, performance could be affected by failure of other, non-PFC brain areas. Furthermore, task performance necessitates understanding and memory of the rules. While every effort was made to ensure understanding as described above, it is still possible that some children performed poorly, not due to poor inhibition, but due to poor rule comprehension or failure to remember the rules. Lastly, as discussed above, a major limitation of this study is that we began to observe a ceiling effect for the task among 7- and 8-year-olds, limiting the possibility of observing an effect of poverty on trajectory slope that could be present, had the task been more difficult. Thus, while this task could have applications for screening children upon entry to Head Start or pre-kindergarten, it would not have much utility among older children.

*Directions for Future Research*

A number of directions for future research exist. First, this analysis should be repeated after more participants in the YCLS study have had the opportunity to be followed yearly at least three years. This replication would provide both a larger sample size and more participants from families with income-to-need ratios below 2.0 and would therefore have the potential to strengthen our results. Second, studies should continue to examine the effect of poverty on other inhibitory control and executive functioning tasks. A comparison and eventual meta-analysis of these results would help to further identify whether inhibitory control appears to be affected predominately or whether other sub-components of executive functioning (working memory, cognitive flexibility) are also affected or are more strongly affected by growing up in poverty. Third, more studies should be performed that involve non-behavioral measures of inhibitory control and executive functioning, similar to the work of Kishiyama et al. (31). This research could take the form of EEG studies or imaging studies. Fourth, future studies should examine the genetic versus environmental contributions to differences in inhibitory control ability. This research could take the form of twin studies, adoption studies, or genotyping studies looking for polymorphisms that have been associated with executive functioning.

Research will also need to start exploring the potential pathways and mechanisms by which experiencing poverty might affect development of PFC. For example, one study has already shown that a high quality of the home environment, maternal sensitivity, and maternal cognitive stimulation predict better inhibitory control in children as measured by performance on an AX-CPT (74). Broad etiologic categories for potential factors mediating the link between poverty and age 5 inhibitory control include factors related to physical health, factors related to cognitive stimulation, and factors related to home environment, though these categories overlap to some extent.

An important physical factor that could mediate the relationship between income and poor inhibitory control at age 5 is inadequate nutrition, which could include being underweight, being overweight, vitamin deficiencies, and iron deficiency anemia. Other possible physical etiologic factors are increased exposure to cigarette smoke, lead, and other environmental toxins and greater frequency and duration of illnesses due to difficulty accessing appropriate health care.

Mediating factors related to cognitive stimulation might include the quality of learning opportunities in the home and outside of the home (e.g., libraries, museums), the quality of the schools, and the availability of preschool. These types of enriched learning environments can be thought of as increasing the “environmental complexity” in a child’s life. In animal models, environmental complexity has been shown to augment brain development at the cellular level and on tasks of learning and memory (17).

Lastly, mediating factors related to home environment might include parental behavior, beliefs and attitudes, exposure to violence and harsh disciplining techniques, family stress levels, and parental depression, all of which can influence the quality of parent-child interactions. A possible biological pathway by which these home environment factors influence brain development is through increased child stress and elevated cortisol levels. In fact, previous studies have shown a positive correlation between a child's cortisol levels and the mother's SES and depression score (75). In addition, low SES children have been shown to have significantly higher salivary cortisol levels compared with high SES children (75, 76). Thus, future research should try to address the factors that mediate the relation between poverty and poorer executive functioning ability at age 5.

Future experimental research should also try to examine the long-term outcomes of interventions like the Tools of the Mind curriculum. How do children who improve on executive functioning with this curriculum in preschool do later on with respect to general cognitive outcomes? Does this training help close the gap between poor and non-poor children on tests of IQ, language development, school readiness, and achievement? Does it alter the frequency of learning disabilities, grade repetition, and high school dropout among low-income children? In other words, is the proposed association between poverty and poor cognitive outcomes mediated by poor executive functioning?

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