Do neural measures of executive function account for income differences in preschool children's effortful control?

Erika J. Ruberry

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Liliana J. Lengua
Katie A. McLaughlin

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Abstract

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Erika J. Ruberry

Chair of the Supervisory Committee:
Liliana J. Lengua, Ph.D.
Psychology

This study examined whether differences in neural processes of executive attention and inhibitory control accounted for income differences observed in performance on behavioral effortful control tasks. We aimed to clarify what specific mechanisms might underlie the link between the context of low income and diminished executive control development in the preschool period. The study utilized a sample of preschool age children (*N* =117) whose families represented the full range of income, with 32% of families near poverty and another 32% lower income families. Children completed a neuropsychological battery of effortful control tasks, and then completed two executive function measures while EEG was collected. We predicted that differences in ERP (event-related potentials) correlates of the executive function measures would account for income differences observed on the effortful control battery. Performance and ERPs from the executive measures were related to performance on the effortful control battery. Income predicted performance on the effortful control battery, but was not related to ERPs. Potential implications for this lack of association are discussed.

Children’s ability to regulate their behavior and their emotions improves rapidly in the preschool years. Growth in effortful control is thought to underlie these improving abilities. However, children growing up in low-income households tend to demonstrate lower effortful control (Hughes, Ensor, Wilson, & Graham, 2010; Lengua et al., in press; Li-Grining, 2007; Mezzacappa, 2004; Raver, Blair, & Willoughby, 2013). Studies have not yet clearly elucidated the mechanisms by which experiences associated with low income might shape the underlying neural processes that support effortful control. The current study aimed to clarify what specific mechanisms might underlie the link between early risk contexts and diminished effortful control development in the preschool period. We examined whether differences in neural processes of executive attention and inhibitory control accounted for income differences observed in performance on behavioral effortful control tasks.

Effortful control is a core aspect of self-regulation (Derryberry & Rothbart, 1997). It is defined as the temperamental capacity to inhibit a prepotent response in favor of initiating a non-dominant response to match situational demands (Murray & Kochanska, 2002). It is thought to comprise the processes of *executive attention*, which allows for the purposeful shifting of attention to relevant information or away from distracting information, and *inhibitory control*, which is the ability to inhibit automatic or prepotent cognitive, emotional or behavioral responses (Eisenberg et al., 2004; Rothbart & Bates, 2007). Typically, ability to delay gratification is also measured as an additional facet of effortful control. However, given the known differences in regulatory ability between rewarded and non-rewarded contexts (Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Zelazo & Müller, 2002), in an effort to hone in on more purely cognitive and behavioral regulation abilities, this study included only measures of effortful control elicited in “cool” experimental contexts.

The experience of growing up in poverty and the stress associated with such environments has been linked to differences in the prefrontal cortex (PFC) and associated circuitry which mediate executive function (Farah et al., 2006; Hackman & Farah, 2009; Lipina & Posner, 2012; Noble, Norman, & Farah, 2005). However, it is unclear whether neural differences in PFC-mediated activity account for the income differences often observed in performance on executive measures. This study tested whether such neural differences underlie observed income differences in effortful control

To examine the neural correlates of children's executive function, EEG data were collected while children completed two computer-based measures testing executive attention and inhibitory control abilities. From these, event-related potentials (ERPs) in response to stimuli were calculated. The ERP is an averaged measurement of the brain's electrical response to a particular stimulus that evokes a sensory, motor, or cognitive event. When elicited during cognitive tasks, particular components are considered to represent certain aspects of cognitive processing based on their general spatial and more specific temporal properties. Our study focused on activity in networks involving the anterior cingulate cortex (ACC), which is associated with executive attention and the detection of conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Rothbart, Sheese, & Posner, 2007) and the prefrontal cortex (PFC), which is associated with inhibitory control (Wiersema & Roeyers, 2008). Activity in these brain regions, therefore, is thought to underlie effortful control processes, and ERPs originating from these areas serve as highly temporally sensitive neural markers of such processes.

In the EEG literature, several specific ERP components are thought to represent executive attention and inhibitory control processes. One is the N200, or N2, which is thought to represent the recognition of conflict, a necessary precursor to an attentional shift. Another is the

P300, also referred to as the P3, which has been demonstrated in adults and in children (often at a greater latency) to be related to attentional monitoring of stimuli, stimulus evaluation, and inhibition of motor response to a stimulus (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Davis, Bruce, Snyder, & Nelson, 2003). Because our computer tasks were selected to elicit both attentional and inhibitory components, we examined these two components. However, based on previous findings showing a stronger relation between effortful control and the P3 (Wiersema & Roeyers, 2008), as well as some emerging evidence that the N2 component may not be observed in children younger than 6 years old (Buss, Dennis, Brooker, & Sippel, 2011), it was unclear whether an N2 would be observed in this sample.

Evidence on associations of SES or income with these ERP correlates of executive attention and inhibitory control is mixed, with some studies finding income-associated performance and brain differences, and others not. Differences in developmental stage and task specifics (e.g., auditory versus visual modality) make it difficult to glean consistent patterns. One study examined SES differences in children 7-12 years old who performed a target detection task that included infrequent novel stimuli (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2008). They saw no task performance differences in this group, which may be attributable to the intentional simplicity of the task and the age of the children studied. Income group differences in ERPs were not observed in detection of target stimuli. Income group differences were observed in the N1 and P1 ERPs to the standard (non-target) stimuli, suggesting early attentional differences, and in the N2 ERP to the novel stimuli, with children from the lower SES group showing an attenuated response compared those in the higher SES group. These results suggest that children from lower SES backgrounds may have developed compensatory processing mechanisms to support performance on such tasks. Differences were not observed on other ERP components including the P3.

Stevens and colleagues (2009) measured the ERP correlates of an auditory attention task in 3-8 year old children across different levels of maternal education. They found that children whose mothers had a lower level of educational attainment displayed higher amplitude ERP responses to the unattended auditory stimuli, despite similar performance on the task. This suggests a deficit in their ability to suppress attention to irrelevant information and may be related to experiences of greater environmental chaos. D'Angiulli and colleagues (2008) also found significant income group differences in 11-15 year old children's ERPs underlying an auditory selective attention task in the absence of performance differences, supporting the notion that lower income children recruited different neural processes to perform the task equally well. The lack of behavioral differences in each of these studies highlights the importance of directly capturing the more subtle neural differences that may underlie differences in outcomes for children growing up in low-income contexts.

The present study aimed to better understand the relations between income and effortful control by directly measuring the underlying neural correlates of executive attention and inhibitory control using ERP. We examined these relations in preschool-aged children because of the dramatic increase in effortful control observed during that period. We measured income continuously to capture differences across the spectrum of income for the families involved in our study. We hypothesized that the neural measures of executive function would relate to performance on the tasks performed while EEG was collected. Because we hypothesized those ERP differences to underlie children's executive attention and inhibitory control ability, we also predicted that they would also relate to observed income differences in children's scores on our broader effortful control battery of behavioral and neuropsychological tasks, which required those same executive functions.

Method

Participants

Participants were a subsample of a larger ongoing longitudinal study (Project 1, 2, 3, GO!), which was designed to examine the impacts of environment, parenting, and temperament on the development of effortful control during children's preschool years. Each family enrolled in the study consisted of a participating child-mother dyad, with equal numbers of male and female children enrolled at Time 1. In the larger study, participants were assessed at 4 time points beginning when the child was 36-40 months old, with follow-up assessments at 9-month intervals, and the final Time 4 assessments taking place when the children were 63-67 months old. In order to ensure equal distribution across income levels to be able to examine effects of impoverished rearing environments, of the 306 families who participated at Time 1, 29% were at or near poverty (N = 90 at or below 1.5 times the federal poverty threshold); 27% were classified as lower income (N = 83 below the local median income of $58,000 annual income); 25% were middle income (N = 78 greater than the local median and less than the upper income threshold); and 18% fell into the upper income category (N = 54 above $100,000 annual income). The larger study sample was recruited from the greater Puget Sound community via contacts with schools, community centers, churches and day-care settings.

From the larger study, a stratified random sample of 118 families were invited to participate in an additional EEG study immediately following the other assessments *either* at Time 3 (n = 62, when children were 54-58 months old) or Time 4 (n = 56, children were 63-67 months old). The subsample was composed of families randomly selected from one of 3 income categories: at or near poverty, lower income, or middle- to upper-income. From the 118 who consented to take part in the EEG portion of the study, several cases were excluded due to child non-compliance or technical issues during EEG collection, and others were excluded due to insufficient data remaining after data cleaning. For ERP averaging, we employed an 8-trial minimum per task condition in order to include a dataset in analyses. This minimum was selected to ensure that participants from lower income groups were not being disproportionately excluded, which occurred when employing a 10-trial minimum: $X^2(2, N = 53) = 6.54$, $p = .038$. Thus, usable data for 61 participants were included in analyses using the Flanker task and 72 participants' data were included in analyses with the Frogs/Fish task (described below).

Procedures

Families were assessed in offices on a university campus. Procedures and materials were approved by the University of Washington Institutional Review Board (IRB). All parents provided prospective informed consent, and children provided assent prior to data collection. Participants first completed behavioral measures, including the neuropsychological battery of effortful control tasks, and then took a break before continuing with the second portion of the study in which EEG measures were obtained. Prior to data collection, the child was shown the EEG cap and went through an acclimation phase to become comfortable in the testing room, with the equipment and with the experimenters. The order of the two executive function tasks, Flanker and Frogs/Fish, was counterbalanced across participants to control for fatigue and order effects.

Measures

Income. Mothers reported on their current household income from all sources on a 14-point Likert scale that provided a fine-grained breakdown of income at the lower levels facilitating identification of families at the federal poverty cutoff using an income-to-needs ratio (e.g., 1 = $14,570 or less, 2 = $14,571-$18,310, 3 = $18,311-22,050, etc.). The poverty categories were used only for participant recruitment into the EEG sub-study. The continuous 14-point variable representing the full range of income was used for analyses (*M* = 8.53, *SD* = 3.82, Range = 1.00 – 14.00).

Effortful Control Tasks. Effortful control was assessed using a neuropsychological battery of 6 tasks. The Inhibition and Auditory Attention subscales of the NEPSY developmental neuropsychological assessment battery (Korkman, Kirk, & Kemp, 1998) were designed for use with children 5 and older. However, the scales were administered to the children in this study to allow use of identical measures of effortful control longitudinally. Thus, these tasks were difficult for children in this sample. The Inhibition subtest assesses the ability to inhibit a dominant response to enact a novel response. Specifically, children are shown an array of circles and squares and asked to label each shape in an opposite manner (e.g. say circle when shown a square). Scores were the proportion correct responses. Auditory Attention is a continuous performance test that assesses the ability to be vigilant and to maintain and shift selective set. Children are required to listen to a series of words and respond only when they hear a target word, refraining from responses to other words. Scores were the proportion correct responses.

Behavioral inhibitory control was assessed using Bear-Dragon (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996), which requires the child to perform actions when a directive is given by a bear puppet, but not when given by a dragon puppet. Children’s actions were scored as performing no movement, wrong movement, partial movement, or complete movement, with scores ranging from 0-3. Total scores were the proportion of items across both bear and dragon items to the total possible score.

Cognitive inhibitory control was assessed using Day-Night (Gerstadt, Hong, & Diamond, 1994), which requires the child to say “day” when shown a picture of moon/stars and “night” when shown a picture of the sun. Children’s actions were scored 1=correctly providing the non-dominant response, or 0=providing the dominant response. Total scores were the proportion of correct responses.

The Dimensional Change Card Sort (DCCS; Zelazo, Müller, Frye, & Marcovitch, 2003) assesses cognitive inhibitory control, attention focusing and set shifting. In this task, children were introduced to two boxes with slots in the top. Target cards were attached to the front of each box. The target cards included a silhouetted figure on a colored background (star on blue, truck on red). Children were instructed to sort cards first according to shape (6 trials) then according to color (6 trials). The experimenter stated sorting rules before each trial and presented a card labeled according to the current dimension (e.g., on a shape trial, “Here’s a truck. Where does it go?”). If children correctly sorted >50% of cards, they advanced to the next level in which the target cards integrated the sorting properties. Target cards consisted of a colored figure on a white background (blue star, red truck), and children were again instructed to sort according to shape (6 trials), then color (6 trials). If they correctly sorted >50% of the cards, children advanced to the next level in which they were instructed to sort by color if the card had a border on it and by shape if the card lacked the border (12 trials). The score was the proportion of correct trials out of the total 36 possible trials.

Head-Toes-Knees-Shoulders (HTKS) integrates attention and inhibitory control (Ponitz et al., 2008). Children are asked to follow the experimenter’s instructions, but to enact the opposite of the direction (e.g. touch toes when asked to touch head). Behaviors were coded as 0=touched the directed body part, 1=self-corrected, or 2=correctly touched the opposite body part. Total scores were the proportion of the score across items to the total possible score.

Twenty percent of all tasks were independently recoded to assess inter-rater reliability (ICC’s=0.72-0.98).

EEG Executive Function Measures

Frogs and Fish Task. A novel Go-No/Go paradigm was administered using Presentation software (Neurobehavioral System, Inc.). The task was designed to elicit two elements of executive attention, sustained and selective attention, as well as inhibitory control. The participants were instructed to watch the screen and press a button when a target group of stimuli turned blue. At the start of each trial, a white fixation cross was presented in the middle of the screen for 300-500 milliseconds. Then the stimuli, which consisted of frogs and fish arranged in a random pattern on the screen, were presented for 1200 milliseconds. To increase task difficulty, the frogs and fish flickered while on the screen, at 3 and 5 Hz, respectively.

Children were instructed to press a button with their index finger only when the target stimuli for that block (alternately the frogs or the fish) turned from their original color (red or green) to blue. During each block of 12 trials, 25% were “go” trials in which the target animal turned blue (so the correct response was to press the button), 25% of trials were “no-go” trials in which the distractor animal was blue (so the correct response was not to press the button, but inhibition was somewhat difficult because there were blue animals present), and the remaining 50% of trials were “standard” trials in which neither animal turned blue (so the correct response was not to press the button; in this condition there were no blue animals on the screen). No feedback was given. There were a total of 240 trials divided across 20 blocks of 12 trials. Only children who completed a minimum of half the test trials (120 trials) were included in analyses.

Flanker Task. The modified visual Flanker task used was based on the child-friendly paradigm used by Rueda et al. (2004). Each trial began with a white fixation cross presented in the middle of the screen for 300-500 milliseconds. After this, a row of five, blue cartoon fish (3.5 cm in length) were presented against a dark blue background. In 50% of the trials (congruent condition), the flanker fish faced the same direction as the center target fish. For the other 50% of trials (incongruent condition), the flanker fish faced the opposite direction of the center target fish. The direction of the center target fish was pseudorandomly counterbalanced to face left or right. Congruent and incongruent trials were pseudorandomly mixed within trial blocks. The row of fish remained on the screen for up to 5000 milliseconds, or until the child made a response. No feedback was given after their response.

Participants were instructed to focus on the center fish, and to press one of two buttons on a control pad that matched the direction of the center fish. The buttons were covered with pictures of the fish facing in either direction, identical to those featured on the stimulus display. Participants were instructed to place their left and right hand index fingers at rest over these buttons during the trial block, so that they would not need to look down after stimulus presentation. Participants completed 100 trials separated into 10 blocks; only children who completed a minimum of 50 trials were included in analyses.

EEG Collection and Processing

EEG activity was recorded using the Active Two system (Biosemi, Amsterdam, Netherlands). A lycra cap was placed on the child’s head, and 32 Ag/Ag-Cl electrodes were attached and arranged according to the 10/20 international labeling system (American Encephalographic Society, 1994). A small amount of electrolyte solution (Signa Gel; Bio-Medical Instruments, Inc., Warren, Michigan) was applied at each electrode site. The child’s scalp was lightly abraded with the tip of a plastic syringe in order to reduce impedances, and impedances were maintained below 25microvolts. Data were sampled at a rate of 256 Hz.

According to Biosemi's design, the ground electrode during data acquisition was formed by the driven right leg passive electrode and the common mode sense active electrode.

All data were processed offline using the EEGLab and ERPLab programs (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2010) created for Matlab (The MathWorks Inc., Natick, MA, 2000). Data were referenced to the vertex electrode Cz, and was bandpass filtered from .01-30 Hz. Epochs were segmented from -200 to 1500ms around each stimulus onset. The baseline correction period was -200 to 0ms, relative to the stimulus onset, for both tasks. Epochs containing eye-blinks or movement artifacts were visually excluded. Additionally, epochs were excluded if the voltage difference between sensors exceeded 100 microvolts in 6 or more sensors, or if an artifact occurred in a channel of interest (P3, P4, Pz, F3, F4, Fz).

Based on visual inspection of participants' waveforms, the N200 component for each Flanker task condition was measured at frontal sites (F3, F4, Fz) as a peak amplitude between 250-450ms post-stimulus. The P3 component was quantified as a peak amplitude from 400-700ms post-stimulus. For the Frogs/Fish task, the N2 was quantified for each task condition at 250-400ms post-stimulus, and the P3 was 400-700ms post-stimulus. Because we took an individual differences approach examining the relation between children's ERPs and their performance on the executive tasks, we were interested in the individual variability in waveforms across conditions. Nonetheless, the group-averaged waveforms are presented in Figures 1 & 2.

Results

Analytic Plan

A series of analyses were conducted to examine the relations between income, ERP components, executive task performance, and effortful control battery performance. Initial correlations revealed that ERP components were correlated across left, right and central sites for each task within their respective regions. Thus, only ERP components assessed at midline sites (Fz, Pz) were included in subsequent analyses. Correlations among study variables were conducted to determine the plausibility of the proposed relations. We then tested whether performance on the Flanker and Frogs/Fish tasks were related to effortful control battery scores. Finally, we tested our hypothesis that the relation of income to effortful control battery performance would be accounted for by ERPs.

Behavioral Results

Behavioral performance for each task is reported in Tables 1 and 2. Overall, accuracy was slightly lower on the Flanker task, suggesting that it was more difficult for the children. Frogs/Fish performance was near ceiling. For the Flanker, the percent correct on incongruent trials and percent correct overall were significantly correlated with performance on the effortful control battery, indicating they were assessing similar underlying constructs. For Frogs/Fish, the percent correct on “go” trials and percent correct overall were correlated with effortful control battery performance.

Relations Among ERPs and Task Performance

For the Flanker, peak ERP amplitudes for each condition for each component were examined, as was a difference score subtracting congruent peak amplitude from incongruent peak amplitude. The congruent N2 peak was related to accuracy on congruent trials and overall performance (see Table 1), suggesting that a less negative N2 peak was linked to better performance on the congruent trials. Such an association was not found for incongruent trials.

Flanker P3 incongruent peak amplitude was negatively related to accuracy on the incongruent trials, suggesting that a lower amplitude was related to better performance. The Flanker P3 incongruent amplitude significantly predicted the effortful control battery score in a linear regression ($\beta = -.29$, $p = .02$) in a model controlling for family income, child age and gender, and the number of trials included in the ERP average, $R^2 = .30$, $F(5,55) = 4.76$, $p = .001$ (see table 3). Children who showed a more mature pattern consisting of less activation on the difficult, incongruent trials, performed better on the measure of effortful control.

For Frogs/Fish, a difference score of the amplitudes from the go conditions minus the no-go conditions was examined, along with the peak amplitudes from each of those conditions for the N2 and P3. Only the Frogs/Fish N2 difference score was related to performance on that task (see Table 2). It also predicted the effortful control battery score ($\beta = .23$, $p = .05$) when included in a model controlling for income, age and gender, $R^2 = .16$, $F(4,67) = 3.28$, $p = .02$ (see table 4).

Relations With Income

Income was directly related to performance on the effortful control battery, $r(59) = .29$, $p = .03$, such that higher income was related to better performance. However, unexpectedly, income was not related to performance on the Flanker or Frogs/Fish measures, except for a trend toward an association between Frogs/Fish no-go percent correct and income ($r(70) = .23$, $p = .05$). Income was not related to the N2 or P3 ERP components, suggesting that, for this sample at least, income is not related to the basic neural processes that underlie effortful control performance.

Discussion

This study tested the hypothesis that income differences observed in children’s effortful control are accounted for by differences in basic neural processes underlying executive functions. The results showed that ERP components that are thought to represent very basic neural processes subserving effortful control, that is, executive attention and inhibitory control, not only predicted performance on those tasks themselves, but also predicted performance on the composite battery of effortful control tasks, which included additional behavioral and social demands. As has been reported elsewhere for this sample, income did predict effortful control performance on the neuropsychological battery of tasks (Lengua et al., in press), as well as for each task individually. However, income did not predict performance on the executive measures administered during the EEG collection, nor ERP differences.

Our sample included a range of income levels with over-inclusion of lower income families. This is critical for the generalizability of the findings to other children and families across socioeconomic strata. The inclusion of lower SES families was critical specifically to the hypotheses being tested, given that children who typically participate in research studies based on convenience samples tend to be from families with more resources, and thus may have a higher average level of effortful control than children in the broader community who are living in impoverished environmental settings. Including families across a broad range of income levels allows us to better understand these phenomena across the spectrum in which they occur.

However, income was not related to performance on the more basic tasks assessing executive functions during the EEG. Thus, the income differences we observed in the broader behavioral effortful control battery may be related to other task demands or aspects of the assessment context. For example, there may be demand characteristics of the assessment context that differentially affect performance across income level, and which are not well understood due to the scarcity of study designs that recruit not just children in poverty and other risk contexts or children in higher income families, but equally across income risk levels.

Income also did not predict the ERPs underlying performance on the executive measures in preschool-age children, contrary to our hypothesis. This lack of association suggests the possibility that the effects of income are further downstream of the early ERP components we examined. They may have their influence, for example, on higher-level processes during which basic detection of conflict is integrated with motor response. This would account for performance differences on tasks requiring inhibitory control when no differences were observed at the level of stimulus evaluation, such as in the ERP components that we measured.

One limitation of the study design is that the performance on the tasks used to assess ERP was near ceiling. The tasks were intentionally selected not to be overly demanding so that neural responses to stimulus qualities could be assessed for most children. However, one unintended effect was that income differences were not observed. In the absence of income-related differences in basic neural processes serving executive control, future research should identify the sources of income differences in performance on executive measures.

Another limitation of this design is that the EEG portion of the study could only be conducted at one time point, for a subset of the larger study sample. This was due to financial and resource constraints, but we hope to use these data as pilot data for future studies. Unfortunately, the current cross-sectional data prevents us from being able to look at the growth trajectories of the neural P3 component itself. This would allow us to track the relation between behavioral performance on effortful control tasks and the underlying neural processes which may or may not develop in sync with one another. At various developmental stages there may be compensatory mechanisms allowing for similar performance in spite of less efficient neural processing. Or, the P3 itself might look similar across development, but may be complemented by other downstream processes that contribute to different behavioral performance. The longitudinal design of the larger parent study allows us to examine the growth trajectories of particular aspects of effortful control in the children, which will help to delineate developmental changes in specific aspects of effortful control. It may also facilitate identification of opportunities to scaffold these abilities across early development. Understanding the moderating impact of risk factors like poverty, and resilience factors like positive parenting, along the developmental course of effortful control can inform when and how we might tailor interventions.

As is common in studies conducted with preschool-aged children, a substantial number of cases were excluded due to technical problems including artifacts on the EEG. This was likely related to children's movement and could have perhaps been reduced by conducting the EEG portion of the study on a separate day rather than at the end of a long behavioral session. However, great efforts were made through automatic and manual artifact rejection processes and filtering to save as many data points as possible. Because income was a central variable of interest, it was critical that we not exclude cases inequitably across the income groups; yet with a higher threshold, lower-income children were more likely to be excluded. Thus, a compromise was made in selecting an 8-trial minimum standard for inclusion in analyses. It is important to note that there were not substantial differences observed in the relations of the ERPs to performance on the Flanker and Frogs/Fish tasks or to the effortful control scores when data were analyzed using a more typical 10-trial minimum. In fact, the main difference between those thresholds was in the disproportionate exclusion of children from lower income families.

Training in executive function has been shown to be effective, including cognitive inhibition of behavior and developing executive attention through computer games and other fun activities, and this could translate to better self-regulation in day-to-day contexts (Dowsett & Livesey, 2000; Kerns, Eso, & Thomson, 1999). This has major implications for improving school readiness and adjustment, especially in at-risk populations (Eisenberg et al., 2004; Lengua, Bush, Long, Kovacs, & Trancik, 2008; Shoda, Mischel, & Peake, 1990). The relations we found between the ERP correlates of executive function and performance the broader effortful control battery provides further support that training basic executive functions could have farther-reaching effects on children’s abilities to regulate in the many situations that demand it in their daily lives. In order to mediate some of the disadvantage conferred upon children who grow up in low income families, it is critical that future research efforts continue to examine at what levels – neural, cognitive, behavioral, emotional – family income influences the development of effortful control, and by what mechanisms.

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Figure 1. Group averaged ERP waveforms for 61 subjects who had a minimum of 8 clean, correct trials on the Flanker task. ERPs to incongruent Flanker trials are in red; congruent trials are in black.

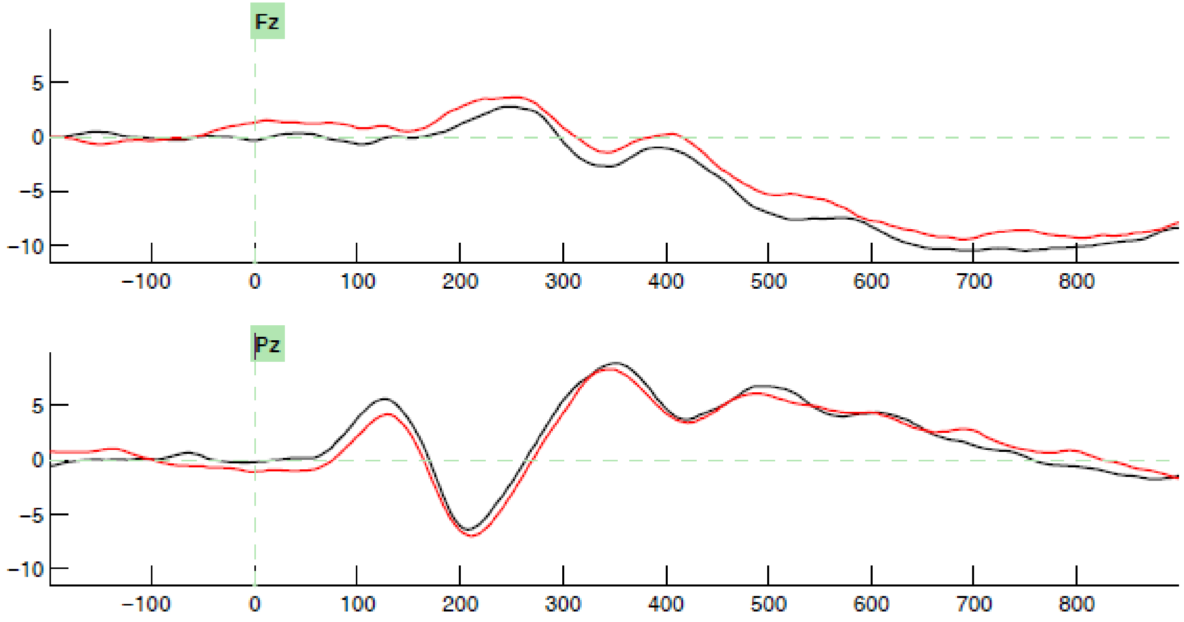

Figure 2. Group-averaged ERP waveforms for 72 subjects who had a minimum of 8 clean, correct trials on the Frogs/Fish task. ERPs to go trials are in black; no-go trials are in red; standard condition trials are in blue.

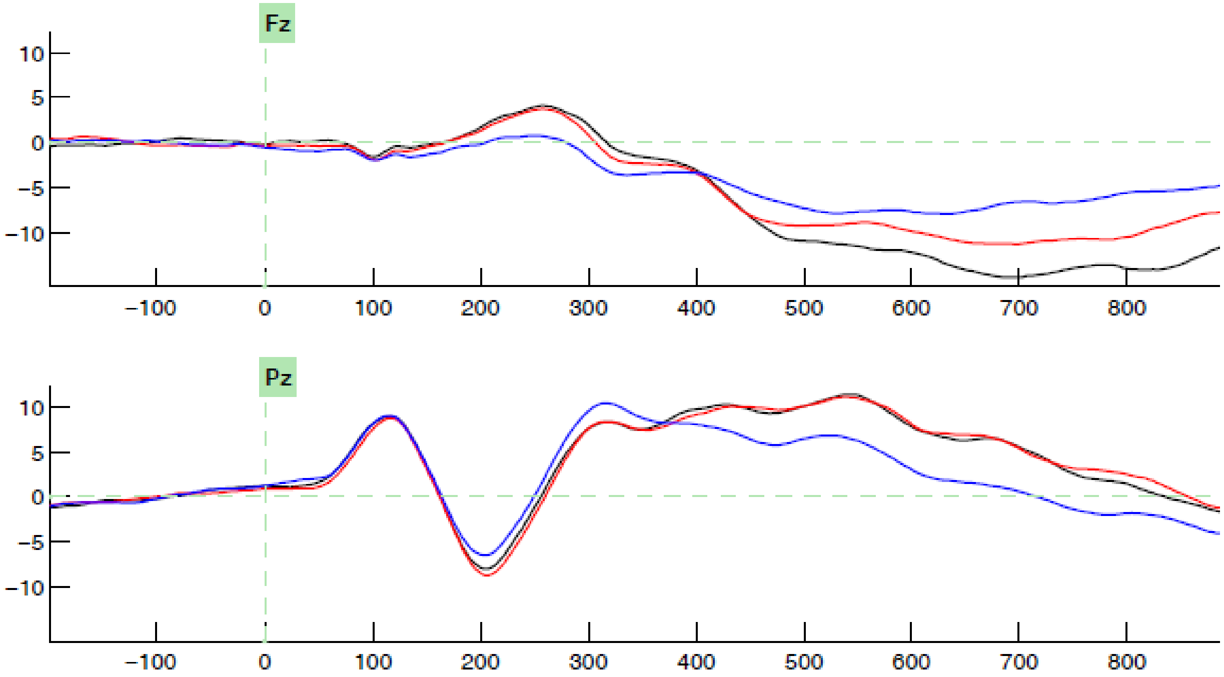

Table 1. Descriptives and correlations for Flanker (n = 61) and other study variables

	M	**SD**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Child gender[a]	--	--	-0.2	-.30*	.14	.07	.11	.08	.00	-.08	.07	.28*	.22
2. Family income	8.90	3.85	--	.29*	.11	.16	.15	.14	.15	.01	-.08	-.18	-.11
3. Effortful control battery score	0.78	0.15		--	.25	.29*	.30*	.05	.04	-.01	-.10	-.38**	-.29*
4. Flanker congruent % correct	0.89	0.14			--	.70**	.90**	.32*	.19	-.12	-.16	-.01	.16
5. Flanker incongruent % correct	0.81	0.18				--	.94**	.15	-.04	-.18	-.30*	-.33*	-.01
6. Flanker overall % correct	0.85	0.15					--	.24	.06	-.17	-.26*	-.21	.07
7. Flanker Fz N2 congruent peak amplitude	-6.28	5.69						--	.43**	-.53**	.01	.05	.04
8. Flanker Fz N2 incongruent peak amplitude	-4.97	5.68							--	.53**	.01	-.04	-.05
9. Flanker Fz N2 difference (incong - cong)	1.30	6.05								--	.00	-.08	-.08
10. Flanker Pz P3 congruent peak amplitude	10.70	7.40									--	.57**	-.50**
11. Flanker Pz P3 incongruent peak amplitude	10.22	7.06										--	.42**
12. Flanker Pz P3 difference (incong - cong)	-0.48	6.69											--

[a] Child gender coded 0 = girl, 1 = boy.

*$p < .05$; **$p < .01$

Table 2. Descriptives and correlations for Frogs/Fish (*n* = 72) and other study variables

	M	**SD**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Child gender[a]	--	--	-.03	-.18	-.15	-.33**	-.32**	.03	.28*	-.26*	.20	.00	.26*
2. Family income	8.94	3.71	--	.10	-.03	.23	.11	-.05	.02	-.06	.04	.12	-.10
3. Effortful control battery score	0.77	0.14		--	.34**	.20	.32**	.13	0.15	.26*	-.10	-.05	-.07
4. Go percent correct	0.93	0.08			--	.05	.62**	.01	0.21	.22	-.12	.02	-.18
5. No-go percent correct	0.86	0.11				--	.75**	.16	0.10	.23*	-.08	-.01	-.09
6. Overall percent correct	0.93	0.05					--	.07	0.18	.23*	-.15	.02	-.22
7. F/F Fz N2 go peak amplitude	-4.59	6.27						--	.42**	.40**	.14	.07	.10
8. F/F Fz N2 no-go peak amplitude	-5.39	7.63							--	-.66**	.04	-.07	.14
9. F/F Fz N2 difference (go - no-go)	0.80	7.56								--	.08	.12	-.06
10. F/F Pz P3 go peak amplitude	15.53	7.55									--	.68**	.42**
11. F/F Pz P3 no-go peak amplitude	15.23	7.40										--	-.38**
12. F/F Pz P3 difference (go - no-go)	0.29	6.01											--

[a] Child gender coded 0 = girl, 1 = boy.

**p* < .05; ***p* < .01

Table 3. Summary of simple regression analyses for Flanker variables predicting effortful control (*n* = 61)

Variable	B	SE B	*β*	t	*p*
Child gender	-0.05	0.03	-0.17	-1.40	0.17
Study timepoint	0.08	0.03	0.28	2.44	0.02
Family income	0.01	0.00	0.23	1.98	0.05
No. trials included in ERP	0.00	0.00	-0.09	-0.73	0.47
Flanker Pz P300 incongruent peak amplitude	-0.01	0.00	-0.29	-2.35	0.02

R^2 = .30

Table 4. Summary of simple regression analyses for Frogs/Fish variables predicting effortful control (*n* = 72)

Variable	B	SE B	*β*	t	*p*
Child gender	-0.03	0.03	-0.11	-0.93	0.36
Study timepoint	0.06	0.03	0.21	1.85	0.07
Family income	0.01	0.00	0.19	1.72	0.09
Flanker Pz P300 incongruent peak amplitude	0.00	0.00	0.23	2.00	0.05

R^2 = .16