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Is Preschool Executive Function Causally Related to Academic Achievement?

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Abstract

The primary objective of this study was to re-evaluate the well-established result that preschoolers' performance on executive function tasks are positively associated with their performance on academic achievement tests. The current study replicated the previously established concurrent associations between children's performance on EF tasks and academic achievement tests. Specifically, children's performance on measures of inhibitory and motor control were positively associated with their performance on tests of reading, writing, and mathematics achievement (rs = .2 –.5); moreover, although diminished in magnitude, most of these associations held up even after including an earlier measure of academic achievement as a covariate (rs = .1 –.3). However, the application of an alternative analytic method, fixed effects analysis, a method which capitalizes on repeated measures data to control for *all time stable measured and unmeasured covariates*, rendered the apparent positive associations between executive function and academic achievement non-significant(rs = .0 –.1).Taken together, these results suggest that the well-replicated association between executive function abilities and academic achievement may be spurious. Results are discussed with respect to the importance of utilizing analytic methods and research designs that facilitate strong causal inferences between executive function and academic achievement in early childhood, as well as the limitations of making curriculum development recommendations and/or public policy decisions based on studies that have failed to do so.

Executive functions (EF) refer to cognitive abilities involved in the control and coordination of information in the service of goal-directed actions(Fuster, 1997; Miller & Cohen, 2001). As such, EF can be defined as a supervisory system that is important for planning, reasoning ability, and the integration of thought and action (Shallice & Burgess, 1996). At a more fine grained level, however, EF, as studied in the cognitive development literature, has come to refer to specific interrelated information processing abilities that enable the resolution of conflicting information; namely, *working memory*, defined as the holding in mind and updating of information while performing some operation on it; *inhibitory control*, defined as the inhibition of prepotent or automatized responding when engaged in task completion; and *attention shifting*, defined as the ability to shift cognitive set among distinct but related dimensions or aspects of a given task (Davidson et al., 2006; Diamond, 2002; Zelazo & Muller, 2002).Focusing on these more narrowly defined abilities is particularly apropos when studying EF in early childhood, as many of the more complex aspects of EF (e.g., abstract thought; goal setting) have an extended developmental course and are not easily measured in very young children(Garon *et al*., 2008).

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EF has been implicated as an important predictor of school readiness (Blair, 2002). Individual differences in EF abilities in early childhood are associated with increased levels of prosocial and decreased levels of disruptive behavior, as well as enhanced academic achievement (Bierman *et al.*, 2009; Brock *et al.*, 2009; Smith-Donald *et al.*, 2007; Thorell & Wahlstedt, 2006). EF is more strongly related to academic than behavioral functioning. Moreover, EF appears to be more strongly related to math than reading achievement, which is theoretically interesting given the presumed involvement of the prefrontal cortex in both solving math problems and completing inhibitory control tasks (Blair & Razza, 2007; Bull *et al.*, 2008; Bull & Scerif, 2001; Espy *et al.*, 2004).

Given the widely known, and thus far largely intractable, income disparities in academic achievement that are evident at school entry, researchers and policy makers alike are increasingly interested in the development and wide-scale implementation of efforts directed at the remediation of the neurocognitive vulnerabilities of at-risk children (Farah *et al.*, 2004; Farah *et al.*, 2006). Indeed, there are a growing number of educational curricula and intervention programs that have been demonstrated to enhance EF in early childhood (Diamond *et al.*, 2007; Rueda *et al.*, 2005; Thorell *et al.*, 2009). It has been suggested that efforts to enhance EF in early childhood may be one means of prevention school failure (Blair & Diamond, 2008). Implicitly, this line of reasoning assumes that EF is casually related to child academic outcomes (i.e., improving EF will lead to corresponding improvements in school readiness). Although causal language is rarely used, this is obviously the primary interest, as demonstrations of non-causal associations between EF and child outcomes are theoretically vacuous (Rutter, 2007).

At least five studies have reported positive associations between EF and academic achievement in early childhood, with correlations indicating moderate sized effects (*r*s =.3 –. 6; Blair & Razza, 2007; Brock et al., 2009; Bull et al., 2008; Espy et al., 2004; Smith-Donald et al., 2007). However, none of these studies fully attended to the numerous child, familial, and/or environmental variables that may account for (confound) the observed associations. For example, the positive association between a child’s performance on EF and achievement tasks may be explainable in part or in whole by household and/or caregiver characteristics (e.g., consistency in schedules, routine engagement in cognitively stimulating activities, the EF ability of caregivers). To the extent that this is true, targeted improvement in EF will in no way foster improved academic achievement—though this is not to suggest that improvements in EF are not important in their own right. At least four other studies, three of which used a direct assessment of child self-regulation that is conceptually similar to EF, utilized lagged analyses(i.e., predicted time 2 academic achievement from time 1 EF while controlling for time 1 academic achievement) to more explicitly attend to potential confounder variables(Matthews *et al.*, 2009; McClelland *et al.*, 2007; Ponitz *et al.*, 2009; Welsh *et al.*, 2010).These studies uniformly reported continued positive associations between individual differences in EF and academic achievement. Although laudable in their intent, we are unaware of an explicit statistical justification for how a lagged approach attends to unmeasured confounders. The systematic failure of previous studies to attend to a wide number of potential confounder variables may serve to undermine the apparent positive association between executive function and child outcomes, including academic achievement.

In the behavioral and social sciences, “covariate adjustment” remains a dominant strategy for attending to potential confounder variables (Morgan & Winship, 2007). In the case of EF and academic achievement, researchers are expected to measure the full complement of potential confounder variables and include each of them as covariates in their regression models. To the extent that there continues to be a unique effect of EF in the prediction of academic achievement, above and beyond potential confounder variables, the implication that EF is causally related to academic achievement is tenable. This is a difficult task. Little theory is available to guide the selection of confounder variables. Beyond our lack of knowledge about what the full complement of confounder variables may be, the covariate adjustment approach introduces practical limitations in that as the number of measured confounders expands, so should the sample size.

Fixed effects analyses (FEAs) represent an alternative statistical approach to covariate adjustment for evaluating whether EF is causally related to academic achievement in early childhood. Two aspects of FEAs make them particularly attractive for testing this question. First, FEAs can be used in studies that rely on observational designs, which is a common feature of the relevant studies described above. Second, FEAs do not require that researchers measure, or even know, the full complement of potential confounder variables. Instead, FEAs capitalize on the availability of longitudinal (repeated measures) data to remove all of the measured and unmeasured *time invariant* characteristics that may confound the association between EF and academic functioning (Wooldridge, 2002). Consider a situation in which researchers measure children’s academic achievement and EF at two points in time that are sufficiently far apart that changes in these variables are tenable (e.g., at the start and end of a typical academic year). In this situation, the association between academic achievement and EF at times 1 and 2 can be represented as follows:

$$\begin{array}{l} Achievement_{i1}=\mu_1+\beta(EF_{i1})+\sum\gamma x_{i1}+\sum\gamma z_i+a_i+\varepsilon_{i1} \\ Achievement_{i2}=\mu_1+\beta(EF_{i2})+\sum\gamma x_{i2}+\sum\gamma z_i+a_i+\varepsilon_{i2} \end{array}$$

The mu (μ) parameters represent the time specific regression intercepts. The beta (β) coefficients represent the unique effect of EF on academic achievement at each point in time. The gamma (γ) coefficients represent the effects of measured time varying (represented by ‘x’) and time invariant (represented by ‘z’) confounder variables. The alphas (α) represent unmeasured time invariant confounder variables (i.e., they represent all of those time stable characteristics of individuals and their environments that may influence achievement but that are not included γ*z terms, above). Finally, the epsilon (ε) parameters represent that part of achievement that is not accounted for by the set of predictors (i.e., residual error). Subtracting the time 1 and 2 equations from each other results in the following equation:

$$(Achievement_1-Achievement_2)=(\mu_1-\mu_2)+\beta(EF_{i1}-EF_{i2})+\sum\gamma(x_{i1}-x_{i2})+(\varepsilon_1-\varepsilon_2)$$

Note that all of the measured (γ*z) and unmeasured (α) time invariant confounder variables have been removed from this “differenced” equation (Allison, 2009). This results in an estimate of the effect of EF on academic achievement that is unbiased by any (measured or unmeasured) time invariant confounder variable. Contrasting the effects of EF on achievement from this latter equation with those from the former equations (which closely resemble the extant research literature) provides a strategy for more rigorously evaluating whether EF is causally related to academic achievement (Wooldridge, 2002). That is, a FEA approach—which in the case of only two measurements is equivalent to regressing the differences of the outcome (here academic achievement) on differences in the predictors (here EF)—provides a stronger test of the potentially causal association between EF and academic achievement than is possible from cross-sectional or lagged associations that characterize the extant literature. More technically, FEA involves within person comparisons, which guard against bias at the expense of a loss of efficiency(Allison, 2009). That is, FEAs provide a stronger basis for inferring potentially causal associations between EF and child academic functioning but do so at the cost of potentially incurring greater uncertainty (bigger standard errors) regarding the precise size of the effect. Given the current state of this literature, we believe that this is a reasonable trade off. We are interested in understanding whether the previously reported positive associations between EF and academic achievement persist after control for all time invariant confounder variables even if it means potentially greater uncertainty in the precise magnitude of the effect.

The primary goals of this study are to (1) replicate the associations between two widely used measures of EF (pencil tapping as an indicator of inhibitory control; walk a line slowly as an indicator of motor control) in early childhood with multiple indicators of child academic functioning using analytic approaches that are common to this literature(and that largely ignore potential confounder variables) and (2) re-evaluate these associations using a fixed effects analysis (which attends to all measured and unmeasured time-stable confounders). To the extent that results are consistent across statistical methods(i.e., performance on executive function tasks is positively correlated with performance on academic achievement tests), inferences about the causal effect of EF on academic functioning are strengthened. However, if the results using fixed effects analyses diverge from the more commonly used methods(i.e., the previously established positive association between EF and academic achievement is rendered non-significant), this raises questions about potential spurious associations between EF and academic functioning due to presence of unmeasured of confounder variables.

Methods

Study Design, Participants,& Procedure

Data were drawn from the Building Bridges project, a cluster randomized study that tested the efficacy of a newly developed curriculum that was designed to enhance preschool children’s social, behavioral, and academic functioning. A full description of this study appears elsewhere, and readers interested in a full account of treatment effects are referred to that manuscript (Kupersmidt et al, 2010). The current study makes use of EF and achievement data that were collected at pre-and post-test (i.e., Fall and Spring)assessments of an academic year, using overall treatment status as a covariate. Hence, for our intent and purpose, this dataset can be conceived of as an observational design study in which EF and academic achievement was measured two times during an academic year. This closely approximates (or subsumes) the majority of previous studies that have investigated the association between EF and academic achievement in early childhood.

Head Start (47%) and child care (53%) programs serving 4-year-old children were recruited. Child care centers were identified in the same counties as Head Start centers and were required to serve primarily low-income families. Due to resource limitations, 794 (86%) of 926 total children who participated in the study were administered direct assessments of EF and included in this study. Relative to children who were not tested, children who were tested were less likely to be enrolled in Head Start Centers (47% vs. 67%, $p < .0001$), less likely to be receiving treatment (70% vs. 81%, $p = .009$), and were slightly older (Ms=4.6 vs. 4.5 years, $p < .0001$). However, children who were tested did not differ from untested children with respect to teacher-reported inattention-overactive (Ms = 1.0 vs. 1.0, $p = .43$) or oppositional-defiant (M = 0.7 vs. 0.6, $p = .09$) behaviors measured at pre-test, or in gender distribution (51% vs. 45%male, $p = .25$). Descriptively, participating children were 51% male, 59% African American (33% Caucasian, 7% Hispanic, 2% other race/ethnicity; percentages due not sum to 100 due to rounding), and, on average, 4.6 years old (inter-quartile range 4.4–4.9years; total range: 3.1–5.8 years)

Measures

Executive Function—The Preschool Self-Regulation Assessment (PSRA; Smith-Donald et al., 2007)represents a collection of brief, direct assessments of children's self-regulatory abilities that are standardized for use in large scale studies. Tasks from the PSRA have been successfully utilized in at least three large-scale studies that are similar to the current study (Bierman *et al.*, 2008; Raver *et al.*, in press; Rimm-Kaufman *et al.*, 2009). The current study used two tasks from the PSRA.

In the Balance Beam task (also known as Walk a Line Slowly) children are asked to walk a 6′ line (masking tape on floor)three times, in each instance being prompted to walk more slowly than the previous time. The difference between the fastest and shortest walk times was used as an index of motor inhibition. All data collectors underwent training and certification at task administration. Moreover, Smith-Donald et al. (2007) reported high levels of inter-rater reliability for recording of child walk times in their study (ICC = .98). In the Pencil Tapping task(also known as Peg Tapping), the assessor and the child each have a pencil. Children are instructed that when the assessor taps her pencil one/two time/s, the child is to tap his/her pencil two/onetime(s). After a series of (up to six) practice trials, in which the assessor provided feedback to the child, 16 scored trials were administered in which no feedback was provided to the child. The number of correct responses is used as an index of inhibitory control. Items exhibited good internal consistency at pre-and post-test assessments (KR-20s = .89 and .91, respectively). Smith-Donald et al. (2007) also reported perfect levels of inter-rater reliability for recording of child responses in their study (ICC = 1.0).

Academic Achievement—*Woodcock-Johnson III: Tests of Achievement* (WJIII; Woodcock et al., 2001). Three subtests of the WJ-III tests of achievement were administered: Applied Problems(Math), Letter-Word Identification, and Sound Awareness (Rhyming). The Letter-Word Identification subtest is a measure of the child's ability to identify letters and words. Split-half reliability for 4-year old children was reported to be .97. The Applied Problems subtest assesses the child's mathematical skills. Split-half reliability for 4-year old children was reported to be .94. The Sound Awareness (Rhyming) subtest assesses phonological awareness. The rhyming section has some initial items that require a pointing response. Later items require an examinee to provide a word that rhymes with a stimulus word. Split-half reliability for 4-year old children was reported to be .71.

Analytic Strategy

Three sets of mixed linear regression models, which accommodated the non-independence of observations (children in classrooms), were estimated for each academic outcome. The first model regressed pre-test achievement on pre-test EF and demographic covariates. The second model regressed post-test achievement on pre-test EF, demographic covariates, and pre-test achievement. The third model regressed changes in achievement on changes in EF. The first and second models approximated previous studies that relied on cross-sectional or lagged associations. The third model was a fixed effects analysis for the case with two repeated measures. In order to establish a common metric for interpreting all of the results, achievement and EF measures were standardized with reference to their pre-test score. Hence, unstandardized regression coefficients for EF measures represent the amount of change in achievement (in standard deviation units) that result from a hypothesized one standard deviation unit change in EF. As such, standardized coefficients are not reported.

Results

Descriptive Statistics

Table 1 summarizes descriptive statistics for the two measures of EF and the three measures of academic achievement, in their *raw* metrics. On average, pre-and post-test assessments spanned 4.4 months (inter-quartile range: 3.0 – 4.9 months; total range 1.5 – 8.1 months). Paired t-tests indicated that, on average, children improved on all five measures from pre-to post-test, though this was not uniformly true (some children performed worse on each task/ test at post-than at pre-test). Importantly, it is variation in differences scores, not some minimum amounts of absolute change, that is important for the use of fixed effects analyses.

EF and Achievement

Table 2 summarizes the results of 9 regression models in which pencil tapping was the focal predictor. Performance on the pencil tapping task was significantly related to all three achievement scores at pre-test (rs = .39 –.49, ps < .001). Although decreased in magnitude, pre-test pencil tapping continued to be significantly associated with all three achievement scores at post-test even after controlling for achievement at pre-test (partial rs = .10 –.27, ps < .02). However, changes in pencil tapping were unrelated to changes in achievement (rs = .01 –.03, ps > .05). To clarify the interpretation of Table 2, a one–standard deviation unit increase in pencil tapping was associated with .37, .21, and .03 standard deviation unit increases in applied problems for cross-sectional, lagged, and fixed effects models, respectively. Whereas the former two effects were statistically significant, the latter was not.

Table 3 provides a comparable set of results when balance beam was the focal predictor. Pre-test balance beam was significantly related to all three achievement scores at pre-test, (rs = .16 –.25, ps < .001), although the strength of the associations was appreciably smaller than for pencil tapping. Whereas pre-test balance beam was significantly associated with applied problems (partial r = .13, p < .001)and rhyming (partial r = .08, p =.04)at post-test, even after controlling for pre-test values of these same measures, it was not significantly associated with letter-word achievement at post-test after controlling for pre-test letter-word achievement (partial rs = .07, p =.07). Finally, there was no evidence that changes in balance beam were significantly related to changes in achievement (rs = .02 –.07, ps > .05)[i].

Discussion

Replicating numerous other studies, preschoolers who performed well on EF tasks also performed well on tests of academic achievement. This was observed for two different measures of EF and three different measure of academic achievement. Moreover, the pencil tapping task continued to exert a unique and statistically significant association with post-test measures of academic achievement even after controlling for pre-test measures of academic achievement (the balance beam also exerted a significant lagged association with applied problems). In contrast, fixed effects analyses, which controlled for all measured and unmeasured time invariant confounders, did not provide any support for the unique association between measures of EF and academic achievement.

The magnitude of the cross-sectional associations reported in this study (rs = .1 –.5) are very similar to those reported in previous studies. This was especially true for the inhibitory control (pencil tapping) task, which is arguably a better indicator of the construct EF than is

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[i] The use of difference scores as independent and dependent variables in mixed linear regression models resulted in the exclusion of all data for children who did not participate at both pre-and post-test assessments. Sensitivity analyses were conducted using a structural equation modeling approach that permitted the inclusion of all observations for all children. Substantive conclusions were unchanged. These results are available by request from the first author.

the motor control (balance beam) task. Moreover, the results of lagged analyses were also consistent with previous studies in demonstrating a continued unique effect of EF on achievement, albeit reduced in magnitude, above and beyond the contributions of an earlier measure of academic achievement. Taken together, these results suggest that the current study is comparable in many ways to other studies that have addressed this issue. It is from this vantage that the fixed effects analyses should be interpreted. Whereas we replicated cross-sectional and lagged associations between EF and academic achievement, the FEAs rendered these associations non-significant. That is, when we applied a statistical approach that controlled for all time stable influences on academic achievement, including those that were unmeasured in this study, there was no longer evidence for a unique association between EF and academic achievement. This raises the possibility that EF is not causally related to academic achievement.

Although a variety of other statistical methods exist which may be used to test whether EF is causally related to academic achievement in early childhood (e.g., propensity score models; instrumental variables estimators), the use of randomized designs continue to represent the gold standard for causal inference. Indeed, many modern statistical approaches that are used to infer causal inferences from observational data are motivated by consideration of the hypothetical experimental design that would have yielded the observed data at hand (Rubin, 2008). Whereas a growing number of randomized treatment studies have reported enhancements to EF abilities in preschoolers, we are not aware of any that have demonstrated that treatment effects on EF mediate corresponding improvements in academic functioning (Diamond *et al.*, 2007; Rueda *et al.*, 2005; Thorell *et al.*, 2009). The availability of curricula and/or programs that have been demonstrated to improve EF will provide the strongest tests of whether EF is causally related to academic achievement. However, randomized controlled trials are costly, time consuming, and often difficult to implement with high fidelity. In the absence of such opportunities, we believe that the application of statistical methods that more explicitly attend to potential confounder variables is warranted.

This study is characterized by at least three limitations. First, our measurement of EF was admittedly limited. The parent study upon which this study is based sought to enhance kindergarten readiness through the delivery of a universally applied educational curriculum, including professional development activities for teachers. EF did not figure prominently into its theory of change. Although both the balance beam and pencil tapping tasks are widely used and appropriate measures for four-year old children, the administration of a greater number of EF tasks, including tasks that measure other putative dimension of EF (working memory, attention shifting), may have provided a stronger test of the motivating questions. Nonetheless, our replication of effects from other studies indicates that measurement issues, alone, do not contribute substantially to the conclusions drawn. Second, fixed effects capitalize on repeated measures data to “difference away” any time stable confounder effects. To the extent that true change in predictor and/or outcome variables is not observable in the time interval studied, fixed effect analyses are not beneficial. This is related to the well known fact that the reliability of differences scores varies as a function of whether individual differences in change across time are evident (Rogosa & Willett, 1983). Although the current study demonstrated that statistically significant changes occurred in both predictors and outcomes during the time interval studied, future studies, which span a longer period of time and result in greater variability in change, may provide a stronger test of the effect of EF on achievement. Third, although not specifically a limitation of this study, it is worth emphasizing that fixed effects analyses are by no means a panacea for the problems of inferring causal effects from observational designs. Fixed effect analyses often reduce bias at the expense of efficiency. Moreover, fixed effects analyses only control for confounder variables that are time invariant. They are unable to control for time varying confounder variables (i.e., including confounder variables that exert differential influence on EF and/or achievement across time).

In sum, research on executive functioning in early childhood has witnessed dramatic growth in the last decade and shows no sign of abating. The vast majority of this research relied on observational designs and reported associations between EF and other aspects of child functioning (e.g., externalizing behavior, academic achievement, theory of mind) without attending to the numerous child, family, and household characteristics that may confound the reported associations. Moreover, remarkably little theory or empirical research is available for researchers to draw on to inform the selection of appropriate control variables. Taken together, we see a pressing need for the greater application of analytic methods and the use of research designs that facilitate strong causal inferences regarding the association of EF and child outcomes. This work is critically important for knowing whether investments in programs and policies that are designed to enhance EF abilities in early childhood will bring about long term improvements in functional outcomes (Heckman, 2007).

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Table 1

Descriptive Statistics (Raw Metric)

	Pre-test			Post-test			Difference			Change
Variable	**N**	**M**	**SD**	**N**	**M**	**SD**	**N**	**M**	**SD**	**T**
Pencil Tap	757	9.2	4.9	700	11.1	4.8	663	2.0	4.2	11.9***
Balance Beam	756	4.4	5.3	701	6.1	7.1	663	1.6	6.8	6.2***
WJ-AP	762	11.1	4.3	718	13.0	4.3	684	1.8	3.2	14.7***
WJ-LW	765	8.0	4.3	717	9.9	4.4	686	1.8	3.1	14.7***
WJ-Rhyme	763	2.6	3.2	717	4.2	4.0	687	1.5	3.1	12.4***

Note: Difference = Post – Pre; Change = paired t-test of post-pre; N = Sample size; M = Mean; SD = Standard Deviation; WJ =Woodcock Johnson III;AP = Applied Problems; LW = Letter Word Identification; Rhyme = Rhyming

Table 2

Summary of Regression Coefficients Relating Academic Performance to Pencil Tapping.

	WJ – Applied Probs			WJ – Letter Word			WJ – Rhyming		
	Pre-test B (SE)	**Post-test B (SE)**	**Difference B (SE)**	**Pre-test B (SE)**	**Post-test B (SE)**	**Difference B (SE)**	**Pre-test B (SE)**	**Post-test B (SE)**	**Difference B (SE)**
Age	.73 (.09) ***	−.10 (.08)	--	.55 (.10) ***	−.02 (.08)	--	.32 (.10) **	.14 (.11)	--
Male	−.06 (.06)	−10 (.05)	--	−.11 (.06)	−.03 (.05)	--	−.14 (.06) *	−.04 (.07)	--
Head Start	−.53 (.08) ***	−.13 (.07) *	--	−.15 (.09)	.11 (.07)	--	.09 (.09)	−.03 (.09)	--
Treatment	.08 (.09)	−.08 (.07)	−.08 (.06)	−.03 (.10)	−.14 (.08)	−.13 (.09)	−.15 (.10)	−.04 (.10)	.05 (.08)
Pencil Tapping^A	.37 (.03) ***	.21 (.03) ***	.03 (.03)	.28 (.03) ***	.06 (.03) *	.02 (.03)	.34 (.03) ***	.21 (.04) ***	.02 (.04)
Pre-test Outcome	--	.59 (.03) ***	--	--	.73 (.03) ***	--	--	.66 (.04) ***	--

Note:

* $p < .05$;

** $p < .01$;

*** $p < .001$;

B = unstandardized regression coefficient; SE = standard error of regression coefficient; A – Using pre-test score as predictor of pre-test and post-test outcomes but using difference score (EF post-test – EF pre-test) when predicting differences in outcomes (achievement post-test – achievement pre-test).Whereas results in the columns labeled pre-test and post-test do not attend to unmeasured confounder variables, the results in columns labeled difference do and are equivalent to fixed effects analyses for the special case two panel designs.

Table 3

Summary of Regression Coefficients Relating Academic Performance to Balance Beam

	WJ – Applied Probs			WJ – Letter Word			WJ – Rhyming		
	Pre-test B (SE)	**Post-test B (SE)**	**Difference B (SE)**	**Pre-test B (SE)**	**Post-test B (SE)**	**Difference B (SE)**	**Pre-test B (SE)**	**Post-test B (SE)**	**Difference B (SE)**
Age	.92 (.10)***	−.05 (.09)	--	.70 (.10)***	−.01 (.08)	--	.50 (.10)**	.22 (.11)	--
Male	−.12 (.06)	−12 (.05)*	--	−.16 (.06)*	−.04 (.05)	--	−.20 (.07)**	−.07 (.07)	--
Head Start	−.59 (.09)***	−.13 (.07)*	--	−.20 (.10)	.10 (.07)	--	−.15 (.10)	−.08 (.09)	--
Treatment	.12 (.10)	−.06 (.07)	−.09 (.07)	−.01 (.11)	−.13 (.08)	−.13 (.09)	−.11 (.11)	.01 (.10)	.06 (.09)
Balance Beam^{A}	.18 (.03)***	.08 (.03)**	.02 (.02)	.12 (.03)***	.02 (.03)	−.01 (.02)	.16 (.03)***	.06 (.04)	.05 (.03)
Pre-test Outcome	--	.66 (.03)***	--	--	.74 (.03)***	--	--	.72 (.04)***	--

Note:

$^{*}p < .05$;

$^{**}p < .01$;

$^{***}p < .001$;

B = unstandardized regression coefficient; SE = standard error of regression coefficient; A – Using pre-test score as predictor of pre-test and post-test outcomes but using difference score (EF post-test – EF pre-test) when predicting differences in outcomes (achievement post-test – achievement pre-test).Whereas results in the columns labeled pre-test and post-test do not attend to unmeasured confounder variables, the results in columns labeled difference do and are equivalent to fixed effects analyses for the special case two panel designs.