Preschool Self-Regulation and Pre-Academic Skills as Mediators of the Long-Term Impacts of an Early Intervention

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Abstract

This study explores children's early academic and self-regulatory skills as potential pathways through which a preschool enrichment program – the Chicago School Readiness Project (CSRP) – may contribute to low-income children's long-term outcomes (N = 466; M age at baseline = 4.10 years). We find that CSRP's impact on high school grades may be partially explained by early gains in vocabulary and math skills. Although impacts on high school executive function (EF) were more equivocal, our results suggest that early improvements in math skills attributable to the intervention may, in turn, predict long-term gains in EF skills. These results complement the existing literature on preschool fade-out, while also shedding light on the cross-domain relations between academic and self-regulatory skills.

Key words: early intervention; self-regulation; academic schools; Head Start; fade-out

Preschool Self-Regulation and Academic Skills as Mediators of the Long-Term Impacts of an Early Intervention

Early childhood programming has long been touted as a means for improving both individual and societal wellbeing. Decades of research have shown immediate, positive impacts of high-quality preschool-based interventions on children's school readiness, including both their pre-academic and social-emotional functioning (Barnett, 2011; Camilli, Vargas, Ryan, & Barnett, 2010; Currie, 2001). Evidence on longer-term impacts, however, is mixed, with many studies showing "fade out" of cognitive effects as children enter elementary school (Barnett, 2011; Puma et al., 2012), and others showing persistent or "resurrected" impacts on academic, health, economic, and behavioral outcomes into adulthood (Gorey, 2001; McCoy et al., 2017; Reynolds et al., 2007). This conflicting evidence has led to questions regarding what early changes in children's skills might account for preschool program fade out versus persistence (Bailey, Duncan, Odgers, & Yu, 2017; Duncan & Magnuson, 2013). Given recent increases in state- and federally-funded preschool participation (Friedman-Krauss et al., 2018), addressing such questions is critical for maximizing program impact and return on public investment.

In the present study, we examine young children's self-regulation and pre-academic skills at the end of the preschool year as a set of developmental processes that may partially account for the long-term impacts of the Chicago School Readiness Project (CSRP). Unlike the comprehensive model programs that are often discussed in the preschool literature (e.g., Perry, Abecedarian), CSRP represents a "new generation" of early intervention studies that aim to test the incremental benefits of services that supplement and/or maximize the impact of existing preschool programs. In particular, CSRP is a teacher professional development and coaching intervention with targeted supports for students that was implemented in Chicago Head Start centers in 2004 and 2005 (Watts, Gandhi, Ibrahim, Masucci, & Raver, 2018). CSRP's theory of change focused on improvements in classroom management and reductions in teacher stress as means for indirectly enhancing student outcomes in several domains (Jones, Bub, & Raver, 2013). Indeed, an early study of CSRP showed that children whose Head Start centers were randomly assigned to receive the CSRP intervention showed significantly greater early math, vocabulary, letter naming, executive function, and attention/impulse control skills at the end of the preschool year compared with their control group peers receiving typical Head Start services (Raver et al., 2011). Recent analyses of the long-term effects of CSRP have shown more mixed results (McCoy et al., 2018; Zhai, Raver, & Jones, 2012), with inconsistent evidence for positive impacts on executive function and more stable evidence for effects on grades in early high school (Watts et al., 2018).

Prior work has shown that early gains in children's school readiness can help to explain the medium-term benefits of preschool participation (e.g., Ansari et al., 2017; Reynolds, Mavrogenes, Bezruczko, & Hagemann, 1996). We build upon this small body of evidence to consider the mechanisms that underlie the longer-run benefits of supplemental services provided by CSRP. In particular, we focus on two primary sets of skills in both Head Start and early high school. First, and in keeping with much of the existing literature on preschool impacts, we examine children's *(pre-)academic skills*, including their math, language, and literacy content knowledge. Second, building on growing evidence regarding the importance of non-academic skill development in early childhood (Denham & Brown, 2010; Ursache, Blair, & Raver, 2012), we also examine a set of relatively under-explored *self-regulation skills,* including both cognitive and behavioral skills in executive function, attention, and impulse and effortful control. Prior research has shown self-regulation and pre-academic skills to be malleable through early classroom-based intervention (e.g., Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Clements & Sarama, 2008; Hamre et al., 2010). Work has also shown these skills to be fundamental, with evidence linking both early self-regulation and pre-academic skills to school readiness, later learning, and adult outcomes (Blair & Razza, 2007; Duncan et al., 2007; Moffitt et al., 2011).

As shown in Figure 1, we explore several alternative pathways through which the immediate effects of the CSRP intervention on children's pre-academic and self-regulation skills may translate into long-term gains in the same domains. First, we consider *within-domain* pathways (see solid bold arrows in Figure 1), where early gains in one domain translate to later advantages in the same domain. Such pathways are consistent with a "skill begets skill" hypothesis of learning, where improvements in basic skills (e.g., basic vocabulary knowledge) lay the foundation for the acquisition of more complex skills in the same domain (e.g., reading comprehension). Second, we explore *cross-domain* pathways (see dotted bold arrows in Figure 1), where immediate gains in one area translate into improvements in a different, but potentially related domain. Consistent with a developmental cascade model, this hypothesis is supported by a large body of cross-sectional and longitudinal research showing positive associations between children's self-regulatory functioning and their (pre-)academic performance (Blair & Razza, 2007; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Bull, Espy, & Wieb, 2008; Matthews, Ponitz, & Morrison, 2009; McClelland et al., 2007; Ponitz, McClelland, Matthews, & Morrison, 2009). In particular, research has shown that basic self-regulatory skills lay the foundation for the more complex goal-directed behaviors and problem solving skills that promote classroom-based learning of academic content (Brock et al., 2009; Ursache, Blair, & Raver, 2012). Conversely, a smaller but emerging body of work also suggests that the abstract and logical thinking involved in learning early academic content – particularly in math – may enhance regulatory skills over time (Clements, Sarama, & Germeroth, 2016).

By testing gains in self-regulation and pre-academic skills during the intervention year as potential mediators of the long-term impact of the CSRP intervention on high school student outcomes, we aim to address several gaps in the literature. First, our use of an experimental, longitudinal design mitigates several methodological limitations of prior literature that attempts to establish directionality in the relations between children's self-regulation and pre-academic skills. Second, our focus on the long-run impacts of a more modern program that aims to enhance preschool quality – rather than establish the benefits of preschool versus parent care – can help to inform the ongoing debate regarding early childhood intervention "fade out" while also supporting quality improvement efforts. In particular, by exploring the early mechanisms that may account for CSRP's longer-term gains, we hope to inform programmatic efforts aimed at reducing achievement gaps and supporting developmental wellbeing for the increasing numbers of young children participating in preschool in the United States.

Method

Procedure & Sample

Data for this study come from the Chicago School Readiness Project (CSRP), an experimental, longitudinal evaluation of a teacher professional development and coaching intervention that took place in 35 Head Start classrooms across 18 centers in 2004 and 2005. Centers were recruited for study participation based on their location in high-crime, high-poverty neighborhoods in Chicago, and were randomly assigned to either the intervention (treatment) or a control condition within covariate-matched site pairs ("blocking groups"). Treatment centers received: (1) five six-hour professional development sessions for lead and assistant teachers focused on behavior management and stress reduction; (2) weekly, in-class coaching for teachers from a master's level mental health consultant (MHC); and (3) regular, one-on-one behavioral supports for selected children provided by MHCs. For further details on the CSRP study's intervention, recruitment, and random assignment, see Raver et al., 2008 and McCoy et al., 2018.

Data for the present study were drawn from three waves of the CSRP evaluation: Head Start fall (baseline), Head Start spring (follow-up 1), and approximately ten years later during the 2015-2016 academic year when children were in secondary school (follow-up 2). Demographic characteristics were reported by primary caregivers at baseline. Trained, multi-lingual data collectors conducted direct assessments of students' self-regulation and pre-academic skills in their Head Start center at baseline and follow-up 1. At follow-up 2, students completed a computerized assessment battery (with the assistance of data collectors) at home or at school, depending on their preference and availability. Because students' age at baseline varied and many students experienced grade retention over time, students' grade at follow-up 2 varied, although the majority (70%) were in early high school and fewer (30%) were in middle school. The analytic sample for the present study comprises 466 students with at least one outcome available at follow-up 2, of whom 236 were in the treatment (CSRP) group and 230 were in the control group. These students represent 77.4 percent of the original 602 students recruited at baseline. Although attrition rates did not differ significantly across treatment and control conditions, the analytic sample was significantly more likely than the full sample to have been in households with four or more children, and to have been in Head Start centers where families were less likely to be employed and more likely to receive TANF at baseline. Children in the analytic sample also had significantly higher baseline early math skills scores relative to the original sample. (See Appendix Table 1 for additional details.)

Baseline demographic characteristics of the analytic sample can be found in Table 1. Briefly, the sample comprised 54 percent girls, 69 percent Black students, 25 percent Latino students, and 3 percent White students. Consistent with the Head Start population, the average income-to-needs ratio of students at baseline was 0.69 (*SD* = 0.58).

Measures

Self-Regulation. At baseline and follow-up 1, students' self-regulation was assessed directly using the Preschool Self-Regulation Assessment (PSRA; Smith-Donald et al., 2007; Raver et al., 2011). Scores from PSRA tasks were standardized (*z*-scored) and aggregated to create two composite scores: executive function was represented using performance on the Balance Beam and Pencil Tap tasks, whereas effortful control was measured using a series of delay tasks (Toy Wrap, Toy Wait, Snack Delay, and Tongue Task). After administering the PSRA tasks, data collectors completed an Assessor Report of children's behaviors during the test session. A total of 18 items from the Assessor Report reflecting children's concentration, distractability, impulsivity, and regulation of arousal were averaged to reflect children's Attention/Impulse Control (possible range = 0 to 3). Cronbach's alphas for the self-regulation tasks across baseline and follow-up 1 ranged from .56 to .93.

At follow-up 2, students' self-regulation was measured using a computer-based version of the Hearts & Flowers task, a measure that specifically targets the executive function subdomain of inhibitory control (Diamond, Barnett, Thomas, & Munro, 2007). Task details are described by Watts and colleagues (2018). Briefly, when a heart appeared on the computer screen, students were asked to click a button on the keyboard that as on the same side as the heart. When a flower appeared on the screen, students were asked to click a button on the opposite side. For the present study, we focus on students' overall accuracy, or the proportion of trials in which they click the correct button, for 33 "mixed" trials including both hearts and flowers. Cronbach's alpha for accuracy was .95. Scores on the Hearts & Flowers task were standardized (*z*-scored) for analysis.

(Pre-)academic achievement. At baseline and follow-up 1, students' vocabulary skills were measured using the 24-item Peabody Picture Vocabulary Task (PPVT; Dunn & Dunn, 1997) or its Spanish counterpart (the Test de Vocabulario en Imagenes Peabody; Dunn, Padilla, Lugo, & Dunn, 1986). Children's letter naming skills were measured using a basic, 26-item task in which they were asked to identify letters of the alphabet. Children's math skills were measured using the 19-item Early Math Skills measure, which covers basic mathematical concepts such as addition, subtraction, and counting (Zill, 2003). Cronbach's alphas for these academic variables at baseline and follow-up 1 ranged from .69 to .97.

At follow-up 2, students' academic skills were captured using self-reported grades. Specifically, students answered the question "How would you describe your grades in school?" with answers coded on a four-point GPA scale (e.g., "mostly A's" was coded as a 4, etc.). Self-reported grades were compared with administrative records for a sub-sample of 141 students (30% of the sample) with available data. The correlation between these methods was .60, and no differences in reporting accuracy were observed across treatment and control conditions. (See Watts et al., 2018 for detailed analyses.) A small number of students ($n = 19$) reported a D average or below despite no evidence for any grade below a C on administrative records. Because of this, we assigned all self-reported grades of C and below to a 2 on the GPA scale, for a final range of 2 to 4.

Covariates. Given prior evidence that relations between self-regulation and academic skills may not be robust to the inclusion of covariates (Jacob & Parkinson, 2015) and the fact that randomization did not lead to full baseline equivalence across treatment and control groups (Watts et al., 2018), we include an extensive list of child-, family-, classroom-, and center-level covariates for analysis. All characteristics listed in Appendix Table 1 were included as covariates. These covariates have been described in detail elsewhere (e.g., McCoy et al, 2018; Raver et al., 2011; Watts et al., 2018).

Analytic Plan

In this study we used path analysis to examine relations between CSRP treatment status and students' self-regulation and academic outcomes at the end of the intervention and again 10 years later. Specifically, random assignment to CSRP treatment was included as the primary predictor variable, students' self-regulation and pre-academic scores at follow-up 1 were included as mediators, and students' self-regulation and academic skills at follow-up 2 were included as outcomes. In addition to direct paths between all primary variables of interest, we included all covariates described in Appendix Table 1 as exogenous variables predicting follow-up 1 and 2 self-regulation and (pre-)academic scores. We also included baseline self-regulation scores as exogenous variables predicting follow-up self-regulation scores, and baseline pre-academic scores as exogenous variables predicting follow-up (pre-)academic scores. Finally, we included covariances between the error terms (disturbances) of the self-regulation and (pre-)academic scores within a given time point (follow-up 1 and follow-up 2).

Full information maximum likelihood (FIML) was used to account for the small amount of missing data on covariates, conditional on all other variables in the model (see Appendix Table 1 for rates of missingness on each set of variables). We used a maximum likelihood estimator with robust standard errors (MLR) and clustered observations at the center level to account for the nested structure of the data. We consider model fit to be adequate based on a

RMSEA of ≤ .06, CFI of ≥ .95, and SRMR of ≤ .08 (Hu & Bentler, 1999). All path analyses were conducted in Mplus (version 7.0; Muthén & Muthén, 1998-2012).

In addition to this primary model, we also examined a series of sensitivity analyses to determine the robustness of our results to alternative model specifications. In particular, we examined models that: (1) replaced the truncated high school grades variable with a raw, non-truncated version; (2) treated high school grades as ordinal rather than interval; (3) used three-level linear regression models similar to those conducted in Raver et al. (2011) instead of path analysis with clustered standard errors; (4) were separated to independently examine high school executive function and grades; (5) examined mediators one-by-one, rather than together in the same model; and (6) combined conceptually similar mediators into two latent variables representing follow-up 1 self-regulation (attention/impulse control, executive function, effortful control) and pre-academic skills (vocabulary, letter naming, early math).. On the whole, sensitivity analyses revealed results that were consistent with those of the primary model and, as such, are not presented here. (For full results of alternative models 1-5, please contact first author. For results of alternative model 6, see Appendix Table 5.) In addition to testing these different model specifications, we also examined an alternative means for testing statistical significance of specific indirect effects. Specifically, we construct Monte Carlo confidence intervals using the approach developed by Preacher and Selig (2008; 2012). Results of this approach are consistent with the results of our primary model and are shown in full in Appendix Table 2.

Results

Correlations between focal variables are shown in Appendix Table 3. The primary path model showed adequate model fit: RMSEA = 0.06, CFI = 0.99, SRMR = 0.01. Full results of this model are reported in Figure 2 and Table 2. Consistent with previously published results (Raver et al., 2011), we find direct impacts of CSRP on pre-academic outcomes in the spring of Head Start (vocabulary: $b = 0.033$, S.E. = 0.011, $p < .01$, $\beta = 0.090$; letter naming: $b = 0.162$, S.E. = 0.025, $p < .01$, $\beta = 0.211$; and early math: $b = 0.090$, S.E. = 0.019, $p < .01$, $\beta = 0.208$). We also see a significant impact of CSRP on students' executive function, $b = 0.188$, S.E. = 0.076, $p < .05$, $\beta = 0.117$. The positive impact of CSRP on attention/impulse control in the spring of Head Start observed by Raver and colleagues (2011) was not replicated in our study, possibly due to differences in either model specification (e.g., our inclusion of disturbance covariances) or sample size. Total effects of CSRP on high school outcomes are shown at the bottom of Table 2. Unlike the results of Watts and colleagues' (2018) preferred model (which used fixed effects for blocking group), using our approach we observe no statistically significant effect of CSRP on high school executive function, $b = 0.073$, S.E. = 0.105, p = ns, $\beta = 0.037$. Consistent with Watts and colleagues' (2018) preferred model, however, we identify a statistically significant and positive impact of CSRP on high school students' grades, $b = 0.235$, S.E. = 0.088, $p < .01$, $\beta = 0.158$. (See Appendix Table 4 for comparisons across our results and those of Watts et al., 2018).

Of the six within-domain paths between Head Start spring and high school outcomes, three were statistically significant or marginally significant. Specifically, executive function in the spring of Head Start was the only self-regulation variable to positively predict high school executive function, $b = 0.117$, S.E. = 0.069, $p < .10$, $\beta = 0.095$. Spring of Head Start vocabulary, $b = 1.335$, S.E. = 0.479, $p < .01$, $\beta = 0.327$, and early math, $b = 0.576$, S.E. = 0.292, $p < .05$, $\beta = 0.169$, were both significantly predictive of high school grades. Of the six cross-domain paths between Head Start spring and high school outcomes, only one statistically significant association was observed. Early math skills in the spring of Head Start were significantly associated with high school executive function, $b = 1.048$, S.E. = 0.383, $p < .01$, $\beta = 0.229$.

Overall, the effects of CSRP on high school outcomes were mediated by gains in Head Start skills. Specifically, despite a non-significant total effect, the overall indirect effect of CSRP on high school executive function was positive and statistically significant, $b = 0.092$, S.E. = 0.028, $p < .01$, $\beta = 0.046$. We observe that this overall indirect impact is almost entirely attributable to CSRP's impacts on early math skills, $b = 0.095$, S.E. = 0.044, $p < .05$, $\beta = 0.048$. We also observe a significant and positive overall indirect effect of CSRP on high school grades, $b = 0.143$, S.E. = 0.048, $p < .01$, $\beta = 0.097$, which can be attributed to CSRP's impact on Head Start vocabulary, $b = 0.044$, S.E. = 0.018, $p < .05$, $\beta = 0.030$, and early math, $b = 0.052$, S.E. = 0.025, $p < .05$, $\beta = 0.035$.

Discussion

The primary objective of the present study was to examine the role of early self-regulation and pre-academic skills as potential mechanisms that might explain the long-term benefits of a preschool professional development intervention for low-income children, the Chicago School Readiness Project (CSRP). Analyses probing within-domain pathways showed that intervention-induced improvements in relatively basic pre-academic skills – including vocabulary and early math – were associated with better student grades in high school. Early gains in self-regulatory skills, on the other hand, were not generally predictive of improvements in high school students' executive function. When examining cross-domain pathways, we found that early gains in math skills attributable to the CSRP intervention predicted gains in students' executive function in high school. We found no other evidence for cross-domain paths in the present study.

From a developmental perspective, the link between early math skills and later executive function provides partial support for a "skill begets skill" hypothesis, whereby early improvements in basic developmental processes lay the foundation for more complex skill acquisition over time. This finding is also consistent with a small but growing number of studies identifying longitudinal links between math and executive function processes (Clements, Sarama, & Germeroth, 2016; Watts et al., 2015; Welsh, Nix, Blair, Bierman, & Nelson, 2010; Wolf & McCoy, 2019). At the same time, the lack of statistically significant associations between early self-regulation skills and later academic outcomes contrasts with previous, non-experimental work (e.g., Blair & Razza, 2007). Several possible explanations may account for these null results. On the one hand, our measure of high school academic outcomes – students' self-reported grades – was relatively weak, which may have introduced noise into our estimates and masked a true association. Alternatively, previous work may have incorrectly identified the directionality of the cross-domain relations between self-regulation and academic skills as the result of methodological challenges (e.g., selection bias; Jacob & Parkinson, 2015). Although our experimental, longitudinal data were better positioned to test bidirectionality in these processes across two neurodevelopmentally salient periods (early childhood and adolescence; Best & Miller, 2010; Nelson & Luciana, 2001; Steinberg, 2005), future work is needed to more robustly establish the causal directions of these associations.

Beyond contributing to the developmental literature on the relations between self-regulation and academic skill growth, the results of this study provide a positive piece of evidence regarding the sustainability of interventions that provide incremental enhancements to existing preschool programming. In particular, our findings suggest that in disadvantaged contexts, efforts to improve preschool teacher wellbeing and classroom management may on their own provide sustained benefits for children's academic outcomes, even in the absence of additional supports for instruction. This finding is consistent with CSRP's theory of change, which posited that reductions in teacher stress and improvements in classroom organization would enhance the sorts of teacher-child interactions and instructional quality characteristics that support academic learning (Jones, Bub, & Raver, 2013; Raver et al., 2008). In turn, we find that these early gains in math and literacy skills may help to lay the foundation not only for accelerated academic development, but also – in the case of math – for improvements in domain-general skills such as executive function. Taken together, these findings support the possible effectiveness of general quality improvement efforts as a means for enhancing both short- and long-term outcomes of urban Head Start participants.

Several limitations of the present study should be noted. First, it is important to recognize that the long-term impacts of the CSRP intervention on high school outcomes are sensitive to model specification (see Appendix Table 4). In particular, although our SEM-based approach replicates the positive effects of CSRP on high school grades seen by Watts and colleagues (2018), it fails to identify their statistically significant effect on high school executive function. Furthermore, the long-term effects of CSRP are not apparent in the absence of a set of covariates that account for baseline imbalance. As such, these results should be considered suggestive rather than conclusive.

Second, our measures of self-regulation and academic outcomes were somewhat limited. In particular, the Hearts and Flowers measure used in high school was a relatively narrow representation of one particular executive function skill – inhibitory control – whereas the measures used in the first Head Start follow-up were conceptually broader. In addition, using self-reported grades as a measure of academic skills in high school has numerous limitations associated with self-report bias, as well as the likelihood that grades represent not only students' academic abilities, but also a set of unmeasured teacher perceptions (e.g., Jussim, 1989). More robust and conceptually diverse representations of these constructs are needed in future work.

Third, sample attrition and our focus on a relatively unique set of at-risk, low-income students preclude the generalizability of these findings. Relatedly, neither the CSRP program nor can the counterfactual condition (Head Start business as usual) can be considered representative of the types of programs or control groups that are being studied in other early intervention research, including the more universal, comprehensive pre-k programs often discussed in conversations about fade out and scale-up (Barnett, 2010; Duncan, Ludwig, & Magnuson, 2007). Additional work is needed to replicate these results in diverse settings using a wider range of program types and counterfactual conditions. Fourth, although we attempt to provide a more internally valid estimate of the within- and cross-domain relations between self-regulation and academic skills by leveraging an experimental, longitudinal design, we nevertheless cannot establish causality given the fact that children's Head Start skills – the mediators – were not themselves randomly assigned. Future work directly comparing the impacts of a strictly academic-focused and a strictly self-regulation-focused intervention is needed to confirm the directionality of these relations.

Despite these limitations, the present study contributes important information to the dialog on early educational effectiveness. In particular, our results suggest not only that interventions to improve preschool programming can have lasting impacts on children's outcomes more than a decade after their initial exposure, but also that these improvements can be explained in part by initial and relatively basic developmental skill gains during the intervention year. At the same time, it would be premature to assume that even the best preschool intervention could serve as a complete "inoculation" against subsequent risk exposure, that different models and approaches would achieve similar results, or, finally, that the same sort of sustained impacts might be observed in contexts facing lower levels of adversity. Moving forward, additional work is needed to identify the best target skills for early intervention, as well as the specific strategies, programs, and policies that might serve to sustain these skills over time.

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Figure 1. Conceptual model of the within-domain (solid bold arrows) and across-domain (dashed bold arrows) relations between children's self-regulation/executive function and academic skills across time, in the context of the CSRP treatment

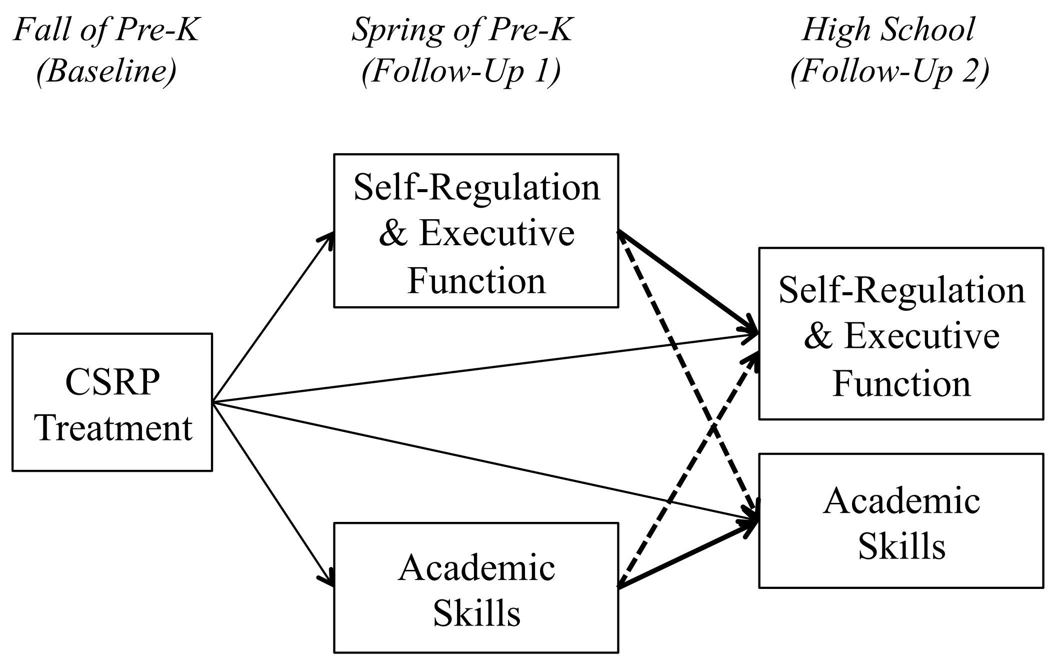
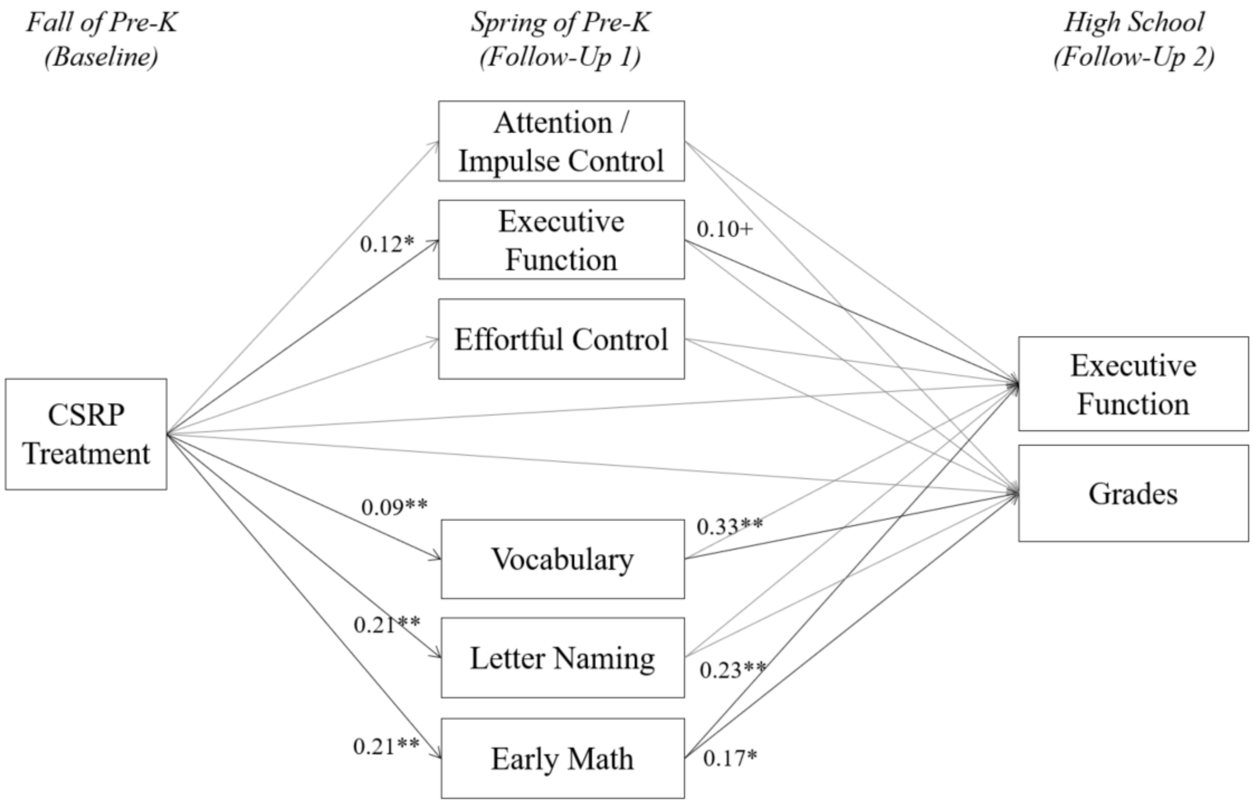


Figure 2. Results of a path model exploring the impact of CSRP on high school outcomes via short-term gains in children's self-regulation and early academic skills



Notes: + $p < .10$, * $p < .05$, ** $p < .01$; All coefficients are standardized. Estimated paths that were not statistically significant are shown in grey and do not include coefficients. Model also included a comprehensive set of child, classroom, and center covariates, including baseline levels of all mediators. Disturbance correlations for the mediators and outcomes estimated but not shown.

Table 1. Descriptive statistics

	M or %	*SD*	*Min*	Max
Child demographics				
Boy	46.1%			
Age (in months)	49.219	(7.252)	31.53	60.80
Black	68.7%			
Latino	24.5			
White	3.0%			
Biracial / other race/ethnicity	3.9%			
Income-to-needs ratio	0.691	0.581	0.00	3.57
Child scores in pre-k fall (Baseline)				
Attention/impulse control	2.268	(0.533)	0.222	3.000
Executive function	0.007	(0.824)	-3.529	2.725
Effortful control	0.018	(0.648)	-2.473	0.687
Vocabulary	0.444	(0.167)	0.00	0.870
Letter naming	0.227	(0.306)	0.00	1.000
Early math	0.400	(0.203)	0.00	0.842
Child scores in pre-k spring (Follow-up 1)				
Attention/impulse control	2.367	0.472	0.500	2.833
Executive function	0.009	(0.814)	-2.124	4.001
Effortful control	0.007	(0.688)	-2.967	0.699
Vocabulary	0.563	(0.183)	0.042	0.958
Letter naming	0.438	(0.386)	0.000	1.000
Early math	0.522	(0.219)	0.000	1.000
Child scores in high school (Follow-up 2)				
Executive function	0.657	(0.194)	0.061	1.000
Grades	2.852	(0.741)	2.000	4.000

Table 2. Results of a path model exploring the impact of CSRP on high school outcomes via short-term gains in children's self-regulation/executive function (SR/EF) and pre-academic skills

	b	*S.E.*	*β*
Direct Paths			
Pre-K Spring (Follow-Up 1)			
SR/EF			
CSRP → Attention / Impulse Control	-0.007	0.050	-0.008
CSRP → Executive Function	0.188*	0.076	0.117
CSRP → Effortful Control	0.056	0.089	0.041
Academic Skills			
CSRP → Vocabulary	0.033**	0.011	0.090
CSRP → Letter Naming	0.162**	0.025	0.211
CSRP → Early Math	0.090**	0.019	0.208
High School (Follow-Up 2)			
SR/EF			
CSRP → Executive Function	-0.018	0.097	-0.009
Attention / Impulse Control → Executive Function	0.158	0.154	0.074
Executive Function → Executive Function	0.117+	0.069	0.095
Effortful Control → Executive Function	-0.070	0.073	-0.048
Vocabulary → Executive Function	-0.140	0.432	-0.026
Letter Naming → Executive Function	-0.094	0.163	-0.036
Early Math → Executive Function	1.048**	0.383	0.229
Academic Skills			
CSRP → Grades	0.091	0.097	0.062
Attention / Impulse Control → Grades	0.065	0.114	0.041
Executive Function → Grades	-0.010	0.088	-0.011
Effortful Control → Grades	-0.018	0.051	-0.016
Vocabulary → Grades	1.335**	0.479	0.327
Letter Naming → Grades	0.316	0.201	0.163
Early Math → Grades	0.576*	0.292	0.169
Indirect Paths			
SR/EF			
CSRP → Attention / Impulse Control → Executive Function	-0.001	(0.008)	-0.001
CSRP → Executive Function → Executive Function	0.022	(0.015)	0.011
CSRP → Effortful Control → Executive Function	-0.004	(0.009)	-0.002
CSRP → Vocabulary → Executive Function	-0.005	(0.014)	-0.002
CSRP → Letter Naming → Executive Function	-0.015	(0.026)	-0.008
CSRP → Early Math → Executive Function	0.095*	(0.044)	0.048
CSRP → Executive Function (total indirect)	0.092**	(0.028)	0.046
Academic Skills			
CSRP → Attention / Impulse Control → Grades	0.000	(0.003)	0.000
CSRP → Executive Function → Grades	-0.002	(0.017)	-0.001
CSRP → Effortful Control → Grades	-0.001	(0.003)	-0.001

CSRP → Vocabulary → Grades	0.044*	(0.018)	0.030
CSRP → Letter Naming → Grades	0.051	(0.033)	0.034
CSRP → Early Math → Grades	0.052*	(0.025)	0.035
CSRP → Grades (total indirect)	0.143**	(0.048)	0.097
Total Effects			
CSRP → Executive Function	0.073	(0.105)	0.037
CSRP → Grades	0.235**	(0.088)	0.158

Notes: + $p < .10$, * $p < .05$, ** $p < .01$; Model also included a comprehensive set of child, classroom, and center covariates, including baseline levels of all mediators.

Appendix Table 1. Full set of baseline covariates in the original and analytic samples, and by treatment status

	Original sample (N = 602)	Analytic sample (N = 466)	*p*-value	Treatment (n = 236)	Control (n = 230)	*p*-value
Child characteristics						
Boy	0.467	0.461	0.624	0.500	0.422	0.008
SD	(0.499)	(0.499)		(0.501)	(0.495)	
Age	49.160	49.219	0.719	49.282	49.154	0.975
SD	(7.383)	(7.252)		(7.317)	(7.200)	
Black	0.658	0.687	0.215	0.708	0.665	0.718
SD	(0.475)	(0.464)		(0.456)	(0.473)	
Latino	0.269	0.245	0.763	0.237	0.252	0.955
SD	(0.444)	(0.430)		(0.426)	(0.435)	
White	0.030	0.030	0.128	0.013	0.048	0.364
SD	(0.170)	(0.171)		(0.112)	(0.214)	
Bi-racial/Other	0.043	0.039	0.394	0.042	0.035	0.699
SD	(0.203)	(0.193)		(0.202)	(0.184)	
4 or more children in household	0.248	0.279	0.007	0.271	0.287	0.361
SD	(0.432)	(0.449)		(0.446)	(0.453)	
Parent Spanish speaking	0.228	0.210	0.355	0.182	0.239	0.363
SD	(0.420)	(0.408)		(0.387)	(0.427)	
Single-parent families	0.709	0.702	0.161	0.720	0.683	0.336
SD	(0.454)	(0.458)		(0.450)	(0.466)	
Family poverty-related risks	0.371	0.363	0.233	0.379	0.345	0.530
SD	(0.326)	(0.326)		(0.327)	(0.324)	
% missing information on teacher/classroom characteristics	0.000	0.000		0.000	0.000	
Baseline scores in Head Start fall						
Vocabulary	0.440	0.444	0.056	0.457	0.430	0.002
SD	(0.163)	(0.167)		(0.159)	(0.175)	
% missing	0.169	0.163		0.169	0.157	
Letter naming	0.216	0.227	0.059	0.246	0.207	0.076
SD	(0.302)	(0.306)		(0.310)	(0.302)	
% missing	0.171	0.163		0.169	0.157	
Early math skill	0.391	0.400	0.043	0.414	0.386	0.094
SD	(0.202)	(0.203)		(0.192)	(0.214)	
% missing	0.169	0.163		0.169	0.157	
Attention/impulse control	2.255	2.268	0.237	2.297	2.239	0.261
SD	(0.546)	(0.533)		(0.516)	(0.550)	
% missing	0.161	0.157		0.169	0.143	
Executive function	-0.009	0.007	0.358	0.109	-0.096	0.013
SD	(0.822)	(0.824)		(0.838)	(0.798)	

% missing	0.163	0.155		0.161	0.148	
Effortful control	-0.000	0.018	0.309	0.053	-0.017	0.595
SD	(0.684)	(0.648)		(0.657)	(0.639)	
% missing	0.159	0.155		0.161	0.148	
Teacher/classroom characteristics						
Teacher has BA	0.676	0.655	0.051	0.708	0.600	0.628
SD	(0.547)	(0.536)		(0.572)	(0.491)	
Teacher age (years)	39.571	39.078	0.267	37.941	40.246	0.189
SD	(9.794)	(9.635)		(8.973)	(10.157)	
Teacher depression (K6) score	2.551	2.638	0.061	3.159	2.104	0.063
SD	(2.005)	(1.996)		(1.534)	(2.259)	
Teacher job demand	2.714	2.696	0.602	2.863	2.524	0.002
SD	(0.591)	(0.592)		(0.623)	(0.505)	
Teacher job control	3.255	3.238	0.264	3.330	3.142	0.488
SD	(0.671)	(0.654)		(0.686)	(0.606)	
Teacher behavior management	4.865	4.826	0.278	4.581	5.077	0.000
SD	(1.032)	(1.032)		(1.074)	(0.923)	
Teacher sensitivity	4.813	4.786	0.482	4.597	4.979	0.011
SD	(1.029)	(1.023)		(0.949)	(1.061)	
Classroom negative climate	2.033	2.077	0.678	2.192	1.959	0.058
SD	(0.978)	(0.977)		(1.097)	(0.823)	
Classroom overall quality	4.708	4.655	0.084	4.432	4.883	0.013
SD	(0.787)	(0.792)		(0.747)	(0.772)	
Number of children aged 3-5	16.435	16.343	0.336	16.508	16.174	0.836
SD	(2.625)	(2.663)		(2.586)	(2.735)	
Number of adults present	2.411	2.402	0.891	2.501	2.301	0.859
SD	(0.692)	(0.680)		(0.767)	(0.561)	
% missing information on teacher/classroom characteristics	0.000	0.000		0.000	0.000	
Site characteristics						
Number of family support workers on staff	1.168	1.238	0.613	0.403	2.096	0.042
SD	(2.251)	(2.391)		(0.491)	(3.147)	
Number of children aged 3-5	109.733	109.882	0.631	91.030	129.226	0.372
SD	(111.585)	(117.735)		(48.208)	(158.176)	
Race/ethnicity (proportion Black)	0.710	0.730	0.290	0.704	0.757	0.080
SD	(0.374)	(0.361)		(0.374)	(0.346)	
Proportion of teachers with a bachelors degree	0.437	0.444	0.545	0.514	0.373	0.408
SD	(0.388)	(0.391)		(0.360)	(0.409)	
Proportion of teacher assistants with college	0.490	0.472	0.140	0.363	0.583	0.006
SD	(0.367)	(0.369)		(0.335)	(0.370)	
Proportion of single families	0.860	0.862	0.903	0.838	0.887	0.512

SD	(0.157)	(0.152)		(0.147)	(0.154)	
Proportion of families employed	0.741	0.724	0.027	0.796	0.650	0.017
SD	(0.262)	(0.265)		(0.222)	(0.284)	
Proportion of families receiving TANF	0.357	0.369	0.010	0.306	0.433	0.272
SD	(0.351)	(0.349)		(0.332)	(0.355)	
% missing information on site characteristics	0.000	0.000		0.000	0.000	

Notes: *p*-values were generated from a series of regressions in which each row variable was regressed on an indicator for treatment status and series of blocking group indicators, with standard errors clustered at the center level.

Appendix Table 2. Indirect effects from primary model with Monte Carlo confidence intervals

	b	*S.E.*	*.95 Confidence Interval*
SR/EF			
CSRP → Attention / Impulse Control → Executive Function	-0.001	(0.008)	(-0.020, 0.027)
CSRP → Executive Function → Executive Function	0.022	(0.015)	(-0.004, 0.059)
CSRP → Effortful Control → Executive Function	-0.004	(0.009)	(-0.035, 0.008)
CSRP → Vocabulary → Executive Function	-0.005	(0.014)	(-0.037, 0.025)
CSRP → Letter Naming → Executive Function	-0.015	(0.026)	(-0.069, 0.037)
CSRP → Early Math → Executive Function	0.095*	(0.044)	(0.022, 0.196)
Academic Skills			
CSRP → Attention / Impulse Control → Grades	0.000	(0.003)	(-0.015, 0.013)
CSRP → Executive Function → Grades	-0.002	(0.017)	(-0.043, 0.031)
CSRP → Effortful Control → Grades	-0.001	(0.003)	(-.0.016, 0.008)
CSRP → Vocabulary → Grades	0.044*	(0.018)	(0.011, 0.084)
CSRP → Letter Naming → Grades	0.051	(0.033)	(-0.012, 0.122)
CSRP → Early Math → Grades	0.052*	(0.025)	(0.001, 0.103)

Notes: + $p < .10$, * $p < .05$, ** $p < .01$; Model also included a comprehensive set of child, classroom, and center covariates, including baseline levels of all mediators.

Appendix Table 3. Correlations between primary variables of interest

	1	2	3	4	5	6	7	8
High School (Follow-Up 2) Outcomes								
1. Grades	1.000							
2. Executive Function	.116*	1.000						
Pre-K Spring (Follow-Up 1) Mediators								
3. Vocabulary	.207***	.172***	1.000					
4. Letter Naming	.190***	.118*	.540***	1.000				
5. Early Math	.225***	.267***	.680***	.691***	1.000			
6. Attention/Impulse Control	.099^{+}	.164**	.341***	.355***	.475***	1.000		
7. Executive Function	.083	.250***	.517***	.454***	.561***	.388***	1.000	
8. Effortful Control	.071	.072	.260***	.246***	.348***	.607***	.310***	1.000
Pre-K Fall (Baseline) Predictor								
9. CSRP Treatment Assignment	.007	.055	.087^{+}	.092^{+}	.033	.008	.055	-.005

Notes: + $p < .10$, * $p < .05$, ** $p < .01$; Cells contain pairwise correlation coefficients.

Appendix Table 4. Comparison of CSRP's total effect on high school outcomes across model specifications

	Primary Model (*with full set of covariates and center-level clustered S.E.s*)	**Unconditional Model** (*no covariate and center-level clustered S.E.s*)	**Fixed Effects Model** (*with child and classroom covariates and fixed effects for blocking group*)
CSRP → Executive Function			
Watts et al., 2018 (linear regression; *n* = 460)	0.042	0.138	0.176+
Current approach (SEM; *n* = 466)	0.073	0.112	0.124*
CSRP → Grades			
Watts et al., 2018 (linear regression; *n* = 418)	0.446**	0.060	0.192*
Current approach (SEM; *n* = 466)	0.316*	0.013	0.132 (*p* = .121)

Notes: All coefficients represent differences between treatment and control groups in *SD* units. "Primary Model" includes the full set of covariates, with standard errors clustered at the center level. "Unconditional Model" excludes covariates and mediators, with standard errors clustered at the center level. "Fixed Effects Model" includes child- and classroom-level covariates, fixed effects for blocking group used for randomization of centers, and standard errors clustered at the center level. Models from Watts et al. (2018) all use traditional regression, whereas our current models use path analysis within a structural equation modeling (SEM) framework with both outcomes modeled simultaneously. Our current models control for a series of child-, classroom-, and site-level covariates used in earlier studies of CSRP (e.g., Raver et al., 2009; Raver et al., 2011; see Appendix Table 1), and use FIML to account for missing data. Watts et al. (2018) include a somewhat different set of child- and classroom-level covariates, in addition to blocking group fixed effects, and use multiple imputation to account for missing data.

Appendix Table 5. Results of a path model exploring the impact of CSRP on high school outcomes via short-term gains in children's self-regulation/executive function (SR/EF) and pre-academic skills, including latent constructs for pre-K spring SR/EF and pre-academic skills

	b	*S.E.*	*β*
Direct Paths			
Pre-K Spring (Follow-Up 1)			
SR/EF			
CSRP → SR/EF	0.025	0.044	0.035
Academic Skills			
CSRP → Pre-Academic Skills	0.059***	0.008	0.206
High School (Follow-Up 2)			
SR/EF			
CSRP → Executive Function	-0.067	0.094	-0.034
SR/EF → Executive Function	0.173	0.353	0.063
Pre-Academic Skills → Executive Function	2.082***	0.392	0.298
Academic Skills			
CSRP → Grades	-0.153	0.119	-0.103
SR/EF → Grades	-0.154	0.241	-0.076
Pre-Academic Skills → Grades	6.353***	1.544	1.223
Indirect Paths			
SR/EF			
CSRP → SR/EF → Executive Function	0.004	0.011	0.002
CSRP → Pre-Academic Skills → Executive Function	0.122***	0.028	0.061
CSRP → Executive Function (total indirect)	0.127***	0.027	0.064
Academic Skills			
CSRP → SR/EF → Grades	-0.004	0.008	-0.003
CSRP → Pre-Academic Skills → Grades	0.374***	0.106	0.252
CSRP → Grades (total indirect)	0.370***	0.103	0.249
Total Effects			
CSRP → Executive Function	0.060	0.098	0.030
CSRP → Grades	0.217*	0.088	0.146

Notes: + $p < .10$, * $p < .05$, ** $p < .01$; Model also included a comprehensive set of child, classroom, and center covariates, including baseline levels of all mediators. "SR/EF" is a latent variable using follow-up 1 Attention/Impulse Control, Executive Function, and Effortful Control as indicators. "Pre-Academic Skills" is a latent variable using follow-up 1 Vocabulary, Letter Naming, and Early Math as indicators. Model fit: RMSEA = .087, CFI = .806, SRMR = .033.