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Early Executive Control and Risk for Overweight and Obesity in Elementary School

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Abstract

An emerging literature suggests that poor executive control may be associated with clinical weight problems (e.g., BMI-for-age percentile ≥ 85 in children). However, our understanding of the impact of executive control on overweight and obesity in childhood is limited by the lack of longitudinal studies spanning critical developmental periods and assessing executive control using comprehensive performance-based batteries. The current study addresses these limitations in a longitudinal examination of 212 children who completed an extensive laboratory-based executive control task battery in preschool (age 4 years, 6 months) and were followed through elementary school (grades 1 through 4) with objective measures of weight status. Logistic regression results indicate that poorer executive control in preschool was associated with significantly greater risk for clinical weight problems (either overweight or obese status, as defined by BMI-for-age percentile ≥ 85) in elementary school, controlling for maternal education. Executive control in preschool was not significantly associated with risk for obese status, specifically (defined by BMI-for-age percentile ≥ 95), but the trend was in the expected direction. Results suggest that early executive abilities are relevant for children's subsequent health status, with deficits in executive control in the critical period of preschool conferring risk for later problems with weight. Based on these findings, early interventions to promote stronger executive control may be a promising, yet currently overlooked, component in pediatric obesity prevention efforts.

Keywords

executive control; preschool; pediatric overweight; pediatric obesity; elementary school

Clinical weight problems are alarmingly prevalent among children, with recent estimates approximating that one-third of all children in the United States are either overweight or obese (Ogden et al., 2014). These problems are in turn associated with a wide range of comorbid chronic health conditions and reduced quality of life (Buttitta, Iliescu, Rousseau, & Guerrien, 2014; Pulgarón, 2013). In the search to identify critical and modifiable child-

level factors that contribute to overweight/obesity risk, executive control (EC) – a set of “top-down” cognitive processes for directing attention and behavior (Garon, Bryson, & Smith, 2008) – has been proposed as a potentially important construct for study (e.g., Martin & Davidson, 2014). An emerging literature suggests a link between poor EC (also known as “executive function”) and overweight/obesity in pediatric samples (e.g., Anzman & Birch, 2009; Pauli-Pott, Albayrak, Hebebrand, & Pott, 2010; Reinert, Po’e, & Barkin, 2013); however, important limitations in existing research undermine our understanding of this association. First, much of the research in this area is cross-sectional, precluding any insight into the directionality of effects. Second, even when longitudinal designs have been utilized, studies are limited by sub-optimal measurement of EC. Specifically, EC is often measured using questionnaires rather than performance-based tasks (e.g., Anzman & Birch, 2009) or studies focus on inhibitory control exclusively (e.g., Pauli-Pott et al., 2010), rather than assessing the full range of abilities typically considered to comprise the broader EC construct (i.e., working memory, inhibitory control, flexible shifting). Third, studies examining EC in *preschool* and associations with subsequent weight problems are lacking. Preschool is widely regarded as a critical period for EC development because of the rapid growth in executive abilities and corresponding neural growth and organization in the prefrontal cortex that occur during this time (see Clark et al., in press, for review).

To address the limitations of existing research, the current study examines EC in preschool, measured using a comprehensive battery of performance-based tasks, as a predictor of subsequent weight status in elementary school in a longitudinal sample. We hypothesized that preschool EC would significantly predict risk for clinical weight problems (i.e., overweight or obese status) in elementary school, with *poorer EC* associated with *greater risk for overweight/obesity*. These hypotheses were based on theory proposing the effects of poor EC on weight status (e.g., Martin & Davidson, 2014), and existing literature linking specific aspects of EC (particularly inhibitory control) with weight problems (e.g., Anzman & Birch, 2009; Pauli-Pott et al., 2010).

Methods

The participants were 212 children (50% female) involved in a larger longitudinal study of EC development. Families with a child in preschool were recruited through flyer distribution in the community. Because the broader study focused on normative EC development, children with a *diagnosed* developmental, language or behavioral disorder at the time of initial enrollment were excluded. Children at higher socioeconomic risk, based on eligibility for public medical insurance, free or reduced lunch status, and/or income-to-needs below the federal poverty line, were oversampled, and 53.3% of the sample used for these analyses were considered high risk at the time of enrollment. The sample was 66.5% Caucasian, 11.3% Hispanic, 3.3% African American, 0.5% Asian, and 18.4% multiracial, which was regionally representative.

All children in the current study participated in a laboratory-based protocol at age 4 years, 6 months as a part of the larger study. During the laboratory visit, each child completed a battery consisting of 9 developmentally-appropriate tasks designed to comprehensively assess critical components of EC. The tasks (described in Table 1), which were administered

by a trained tester in one-on-one sessions, consisted of three working memory tests (*Nine Boxes*, *Delayed Alternation*, *Nebraska Barnyard*), four tasks measuring inhibitory control (*Big-Little Stroop*, *Go/No-Go*, *Shape School - Inhibit Condition*, *modified Snack Delay*), and two tasks measuring flexible shifting (*Shape School - Switching Condition*, *Trails - Switching Condition*). These tasks load on a single latent EC factor.

During the elementary school phase of the study, children returned to the laboratory annually in first, second, third, and fourth grades. In addition to other activities for the broader study, children's height and weight were objectively measured at each of these visits by a trained research assistant using a standard digital scale and stadiometer. Child height and weight were converted to BMI ($\text{weight(lb)} / [\text{height(in)}]^2 \times 703$) and then to BMI-for-age percentiles using the Center for Disease Control and Prevention (CDC) growth charts (Kuczmarski et al., 2000). For the purposes of this study, the last available measurement was then categorized based on whether or not BMI percentile ≥ 85 (corresponding to overweight or obese categories) and whether or not BMI percentile ≥ 95 (corresponding to obese category). Most children had a measurement at fourth grade ($n=177$; 83.5%), and smaller subsets had their last measurement point at third grade ($n=23$; 10.8%), second grade ($n=9$; 4.2%), or first grade ($n=3$; 1.4%).

Two main sets of analyses were conducted to examine the association between EC and subsequent weight status. First, to determine if poorer EC was a risk factor for later clinical weight problems, a logistic regression model was estimated with latent EC in preschool predicting the likelihood of a BMI percentile ≥ 85 at the last measurement point. Second, to determine if poorer EC was a risk factor for obesity, specifically, a similar model with latent EC predicting likelihood of BMI percentile ≥ 95 at the last measurement was conducted. Given that EC and child weight status have both been found to be associated with socioeconomic status, maternal education level (assessed via parent report during the preschool phase) was controlled for in both models. All models were estimated in Mplus 7.31 (Muthén & Muthén, Los Angeles, CA), and a critical α of .05 was used for all tests.

Results and Discussion

Previous confirmatory factor analyses using the current EC task battery at age 4 years, 6 months within the larger longitudinal sample have demonstrated good fit for a unitary EC factor structure (RMSEA = .04; CFI = .96) and that the unitary structure is preferable to both 2- and 3-factor models (Nelson et al., in press). To examine EC as a predictor of risk for subsequent clinical weight problems, a logistic regression was conducted with latent EC in preschool predicting the odds of a BMI percentile ≥ 85 , controlling for maternal education. As shown in Figure 1, EC was a significant negative predictor of having a BMI percentile ≥ 85 , with lower EC associated with greater odds of a BMI in the clinical range (either overweight or obese), [$b = -.47$, $p = .02$, OR = .63], even after controlling for maternal education. Next, to examine EC as a predictor of risk for obesity, specifically, a logistic regression analysis was conducted with latent preschool EC predicting the odds of a BMI percentile ≥ 95 , controlling for maternal education. Contrary to expectations, EC was not a significant predictor of subsequent obese status, [$b = -.32$, $p = .19$], although the trend was in the expected direction. To ensure that the results were not overly influenced by the *modified*

snack delay task, which involves inhibition of responses to food rewards, specifically, we also conducted the above analyses with this task removed from the model. The pattern of results was unchanged, with lower EC associated with greater odds of BMI percentile ≥ 85 , [$b = -.50, p = .01, OR = .61$], but not BMI percentile ≥ 95 , [$b = -.38, p = .14$].

In addition to the primary analyses focusing on weight status, we also conducted supplemental analyses exploring the change in continuous BMI percentiles across elementary school. In a linear growth curve model, latent preschool EC was not a significant predictor of the slope of BMI growth, [$b = .03, p = .59$].

The results of the primary logistic regression analyses partially supported our hypothesis that preschool EC would be related to risk for subsequent weight problems. EC was in fact a significant predictor of risk for clinical weight status – as defined as BMI percentile ≥ 85 , corresponding to either overweight or obese status – with poorer EC associated with a greater risk for unhealthy weight. However, EC did not significantly predict child weight in the more severe obese category. The finding that EC was inversely related to risk for weight problems is consistent with previous findings linking poor EC and unhealthy weight (see Reinert et al., 2013), but extends this literature in important ways. First, the current study's longitudinal framework allowed for analyses of EC truly *predicting* subsequent weight status, in contrast to much of the existing EC-weight research which has been cross-sectional in nature. This is an important step forward in understanding the EC-weight association and beginning to inform possible interventions to ultimately reduce risk for clinical weight problems. Second, the current study employed rigorous and validated measurement of EC, including developmentally-appropriate tasks covering working memory, inhibitory control and flexible shifting. This broad and thorough measurement strategy improves upon previous research in the area that has focused exclusively on inhibitory control. The diverse battery of tasks used in this study provides excellent coverage of the EC construct, broadly conceptualized, and allows for the estimation of a single latent EC factor that best represents the structure of EC in preschool (Nelson et al., in press; Wiebe et al., 2011). Finally, the current study makes an important contribution by assessing EC during the critical period of preschool as a predictor of later weight status. Our results suggest that the abilities emerging during this period may have critical implications for not only cognitive development but also physical health status.

The non-significant results for EC predicting obesity (BMI $\geq 95^{\text{th}}$ percentile) were initially surprising. However, upon further reflection, it is possible that the effect of EC on more severe weight problems may not be evident until later in development. One possibility is that it may take time for these effects to unfold and that the children with low EC who were overweight by elementary school may continue on an unhealthy trajectory of weight gain and move toward obesity in adolescence. Similarly, the effects of EC may be most powerful in adolescence when dietary independence increases substantially (Bassett, Chapman, & Beagan, 2008). Whereas the effects of child EC on unhealthy dietary behaviors (e.g., impulsive and binge eating) in childhood may be somewhat mitigated by parental oversight of food intake (Ventura & Birch, 2008), rapidly increasing food independence in adolescence may heighten the demand for strong EC to direct behavior toward healthy ends, exposing deficits in these regulatory abilities. Consistent with this idea, poor EC in

adulthood is associated with obesogenic risk factors such as unhealthy food choices and overeating (Hall et al., 2015; Limbers & Young, 2015). Ultimately, the current sample may have been too young to fully capture the detrimental effects of poor EC on weight status, and longitudinal studies extending into adolescence and beyond are needed to determine the long-term health risks of low EC. It is also worth noting that EC did not predict the slope of BMI change in elementary school, although this non-significant finding could be related to the limitations of BMI as a continuous measure. Depending on the individual's initial BMI, changes in BMI percentile may or may not correspond to changes in clinical status, so analyses using continuous BMI may obscure the relationship between EC and risk for clinical weight problems.

Although the current study makes important contributions to the literature on EC and weight status, some important limitations and future directions should be noted. First, while this study focused on early EC predicting subsequent weight status, it is possible that EC and clinical weight problems interact in a more bidirectional way. For example, some research suggests that obesity has a detrimental effect on cognition (see Reinert et al., 2013, for review), but our study design did not allow for the examination of this direction of effects. Relatedly, our study did not have BMI measurements in preschool, so analyses could not control for weight early in life in examining weight status later in childhood. Longitudinal research with repeated measurements of both EC and BMI from baseline are needed to more fully explore the causal effect of poor EC on emerging clinical weight problems, as well as the possibility of bidirectional influences across development. A second limitation of the current study is the absence of measures of potential mechanisms through which EC may affect child weight. Previous theoretical (e.g., Martin & Davidson, 2014) and empirical work (Riggs, Spruijt-Metz, Chou, & Pentz, 2012) has highlighted how deficits in aspects of EC may lead to unhealthy diet behaviors and physical inactivity, which may in turn increase the risk for clinical weight problems. Future studies in this area should include assessment of these key health behaviors which may mediate the association between EC and weight status, thus better elucidating the pathways through which EC affects health. Third, our analyses were limited in the covariates included. While our finding that EC predicted clinical weight problems *controlling for maternal education* is important, future research may explore a broader range of potential covariates. Similarly, future research would benefit from examining the role of EC in child weight status within the context of other individual factors that have been linked to obesity risk, such as difficult temperament and reward sensitivity (Anzman-Frasca, Stifter, & Birch, 2012; van den Berg et al., 2011). Finally, it worth noting that the current study oversampled for sociodemographic risk, so caution may be needed in generalizing results to populations with different risk profiles.

The current study could have important implications for intervention and prevention efforts related to overweight and obesity. Our results suggest that EC as early as preschool may be a contributor to weight status, with poor EC serving as a risk factor for unhealthy weight in childhood. This finding points to the potential for interventions to promote EC development during the critical period of preschool as not only a critical part of healthy cognitive development but also in preventing later clinical weight problems. Emerging research suggests that EC may be modifiable and that preschool may be an especially promising period for EC intervention (Diamond & Lee, 2011; Zelazo & Carlson, 2012). Studies

examining the effects of early EC promotion interventions on later weight-related outcomes are needed to test this possibility.

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Figure 1.
Summary of Logistic Regression Results. $*p < .05$

Table 1.**EC Tasks and Descriptions**

Task	Description	Source	Sample Mean
<i>Working Memory</i>			
Nine Boxes	Child searches for rewards among nine boxes of different colors and shapes, keeping in mind previously searched boxes.	Adapted from Diamond et al. (1997)	5.356 (consecutive correct responses)
Delayed Alternation	Child chooses one of two locations on board in search of reward. Child must keep the last location in mind following a delay because location alternates.	Espy et al. (1999); Goldman et al. (1971)	6.098 (longest correct run minus longest incorrect run)
Nebraska Barnyard	Task in which child remembers locations of animal figures on a 3×3 arrangement of squares and indicates location of sequences of animals when pictures are removed.	Adapted from Hughes et al. Noisy Book task (1998)	6.876 (total correct trials)
<i>Inhibitory Control</i>			
Big-Little Stroup	Child must name smaller object embedded within a larger object. "Conflict" trials require suppression of large object name.	Adapted from Kochanska et al. (2000)	.856 (proportion correct on conflict trials)
Go/No-Go	Child presses a button in response to fish on screen but must inhibit response to shark on screen	Adapted from Simpson & Riggs (2006)	2.288 (d' score)
Shape School – Inhibit	Child says the color of cartoon stimulus when face is happy and inhibits naming when stimulus face is sad	Espy (1997); Espy et al. (2006)	.947 (proportion correct on inhibit trials)
modified Snack Delay	Child is asked to remain still in close proximity to candy reward until bell rings	Adapted from Konchanska et al. (1996); Korkman et al. (1998)	22.412 (summary score of hand movement)
<i>Flexible Shifting</i>			
Shape School – Switching	Child says the color of cartoon stimulus when not wearing a hat and says the shape when stimulus is wearing a hat	Espy (1997); Espy et al. (2006)	.738 (proportion correct on switching trials)
Trails - Switching	Child alternates between marking dog and bone stimuli of increasing size with a stamp	Adapted from Espy & Cwik (2004)	.868 (number correct stamp/ total number stamps)

Note: See James et al. (in press) for more detailed information regarding tasks and scoring.