Published in final edited form as:

Child Dev. 2012 May ; 83(3): 1022–1036. doi:10.1111/j.1467-8624.2012.01756.x.

Longitudinal antecedents of executive function in preschoolers

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Abstract

Despite an extensive history underscoring the role of social processes and child contributions to the development of executive functions (Lewis & Carpendale, 2009; Vygotsky, 1987), research on these relations is sparse. To address this gap, sixty-eight mother-child dyads were examined to determine whether maternal attention-directing behaviors (attention-maintaining, attention-redirecting) and toddlers' temperament predicted executive processes during preschool (mean age = 4.5 years, SD = 0.46) - delay and conflict inhibition. Maternal attention-maintaining was associated with high levels of conflict inhibition for inhibited and exuberant children, whereas attention-redirecting was associated with low levels of delay and conflict inhibition for inhibited children. Therefore, maternal attention-directing behaviors may enhance the development of executive functions but only for children with inhibited and exuberant temperaments.

Keywords

executive function; temperamental inhibition; maternal attention-directing behavior

Executive function refers to a set of processes that reflect the ability to flexibly adapt to contextual demands. These processes aid in the monitoring and control of thought and action by biasing processing in favor of task related stimuli and responses despite interference or competing distractions (Cohen, Braver, & O'Reilly, 1996; Zelazo & Cunningham, 2007). Examples include maintaining information in working memory, inhibiting prepotent responses, and voluntarily controlling attention focusing and shifting. Difficulties with executive functions have been associated with various neuropsychological disorders, leading to considerable research focused on fractioning the global construct of executive function to identify distinct processes and neuroanatomical abnormalities (Baddeley, 2002).

Two executive function processes that have received growing attention in the developmental literature include delay inhibition and conflict inhibition. The former requires children to inhibit or delay a prepotent response (Carlson, Moses, & Breton, 2002), whereas the latter also requires that children execute a novel, conflicting response (e.g., read a word on a list of color words, while overriding the desire to state the color in which a word is printed such as in the Stroop task; Stroop, 1935). Children must simultaneously maintain two rules or representations in working memory and execute a novel response. This coordination of executive processes for conflict inhibition is likely dependent upon more complex interactions between frontal and other brain regions than delay and develops late in the preschool years (Garon, Bryson, & Smith, 2008).

Between the ages of 2 and 5 years, dramatic increases in dorsolateral prefrontal cortex (DL-PFC) neuronal growth (Diamond, 2002) also coincide with findings documenting the emergence of individual differences in executive function in the third year of life (Carlson, Mandell, & Williams, 2004). This protracted development, along with the heightened plasticity of the neurocognitive system, provides a window of opportunity for contextual influences, such as parenting behaviors, to shape the development of executive function. Likewise, this renders this developmental period an ideal time to assess early predictors of executive function.

Most research, however, has focused on individual differences and, despite a long theoretical history underscoring social origins, “relations between social interactions and executive function are, in research terms, largely terra incognita” (Hughes & Ensor, 2009, p. 36). The purpose of this study was to address this gap by examining relations between social processes, child characteristics, and the development of executive function. Specifically, we examined the interaction between maternal behavior and toddlers’ temperament on executive function during preschool.

Theoretical Framework

Theorists have long underscored the role of social interaction in the development of higher order executive skills. According to Vygotsky (1981), higher order mental skills reflect voluntary rather than involuntary, automatic reactions. Unlike other species, humans are not at the mercy of automatic, stimulus-response associations, but with the aid of others, develop the ability to inhibit prepotent responses and voluntarily select alternative behaviors. Others serve as external stimuli or controls that function to inhibit and reverse stimulus-response associations. Externally directed inhibition of action creates psychological distance from the pull of the stimulus, and in turn, cultivates opportunities for the development and generation of qualitatively higher forms of behavior (Vygotsky, 1978). Through the support of a more knowledgeable other during socially mediated joint activity, a context is created where alternative and volitional strategies can develop.

This idea has been expanded upon by contemporary theorists who have emphasized the importance of social processes to the development of executive function arguing that prioritized and volitional responses are influenced by cultural values and practices such as parenting (Kopp, 1982, 1989; Lewis, Carpendale, Towse, Maridaki-Kassotaki, in press; Luria, 1973; Rothbart, Posner, & O’Boylan, 1990). In early childhood, parental verbal stimulation, along with warm, positive, responsive, and contingent parenting has been found to longitudinally predict inhibitory control (Kochanska & Murray, 2000; Li-Grining, 2007; Olson, Bates, & Bayles, 1990), whereas negative controlling behaviors, such as power-assertive behaviors and taking over tasks for children have been found to predict poorer delay inhibition (Silverman & Ragusa, 1990).

However, despite these associations, researchers have stressed that unpacking global parenting constructs such as sensitivity and responsivity into more distinct processes will move the field forward in understanding relations to children’s outcomes (De Wolf & van Ijzendor, 1997). Just as parsing the construct of executive function into unique processes led to greater understanding of how various executive processes uniquely or in combination are associated with outcomes such as false belief understanding (Carlson & Moses, 2001), an examination of more specific parenting behaviors may lead to greater understanding of relations between parenting interaction and executive processes. These may include parenting behaviors that support attention, which undergoes significant developmental change across the preschool years (Ruff, Capozzoli, & Weissberg, 1998), and has been

postulated to be a central process underlying executive function (Norman & Schallice, 1986).

From a developmental perspective, volitional attentional control (executive attention) underlies changes in executive function between 2 to 6 years (Rothbart & Posner, 2001). Considerable evidence exists demonstrating that preschoolers who focused attention on an alternative stimulus have longer delays while waiting for a desired object (Mischel, Cantor, & Feldman, 1996; Peake, Hebl, & Mischel, 2002), and children rated higher on attention focusing have also been found to demonstrate better conflict inhibition (Jones et al., 2003). Increases in sustained attention for longer durations and greater focused attention during structured tasks appear to be associated with delay and conflict inhibition.

Adult support of children's attentional focus is also important for successful executive function. The effectiveness of distraction and support by others to attend to alternative stimuli predicts delay inhibition (Miller & Karniol, 1976; Mischel, 1974; Mischel & Ebbesen, 1970). Putnam et al. (2002) examined these processes within mother-child dyads during a delay task when children were 30-months-old. Contingency analysis revealed that co-regulation of attention in the dyad was associated with delay. Successful delay was associated with (1) less time focused on the forbidden toy and more on a distracter, and (2) mothers' support of children's attentional focus.

In sum, supporting and elaborating upon children's attentional focus appears to be a critical predictor of concurrent delay inhibition and may do so by enhancing children's ability to focus attentional resources and concentrate on task demands (Bono & Stifter, 2003). Over time, maternal attention-maintaining may also strengthen children's developing ability to delay and maintain more than one representation and perform an alternative response, as required for conflict inhibition, particularly during sensitive periods of development. However, most findings are based on concurrent as opposed to longitudinal associations and few have included or controlled for child contributions.

In addition to maternal maintaining, mothers also may attempt to redirect their child's attention. When children are distressed, attention redirection is adaptive and speeds emotional recovery (Rothbart, Ziaie, & O'Boyle, 1992; Stifter & Braungart, 1995). However, in contexts when children are not distressed, maternal attention-redirection may be particularly challenging for children and may even be experienced as intrusive as it encourages the child to disengage, shift, and refocus attention on something of interest to the parent (Bono & Stifter, 2003). For example, mothers' redirection of Down syndrome infants' attention has been associated with infants' failure to respond and reduced manipulation of toys (Landry & Chapieski, 1989). When maternal directives (e.g., verbal controlling commands) were made to children, initiative and goal formulation skills at preschool and standardized math scores at 8 years were compromised (Assell, Landry, Swank, Smith, & Steelman, 2003; Landry et al., 2000).

These findings suggest that maternal attention directing behaviors may either facilitate or place additional demands on children depending upon the context. Indeed, for some children, a problem-solving situation with considerable maternal attention-redirection may be experienced as a considerably stressful context. Yet, it is unclear how redirecting children's attention when it is focused on the problem solving task influences subsequent executive function compared to when it is not. In other words, the effect of attention directing may depend on whether the child is on or off task. The purpose of this study was to investigate relations between maternal attention-maintaining and redirecting behaviors and long-term executive function within the context of children's focus of attention. Specifically, we examined maternal attention directing behaviors when children were engaged in

problem-solving and when they were not, and longitudinal relations to child delay and conflict inhibition.

Child characteristics and executive functions

Another important factor involved in executive control is motivation. As stated by Vygotsky (1978), volitional control involves the ability to create psychological distance from the pull of the stimulus (e.g., immediate rewards) to obtain subsequent rewards. Reward or approach behavior must be inhibited in anticipation of a more salient but delayed reward. Therefore, in young children, individual differences in motivations and sensitivities to discomfort or reward likely have a large impact on the ability to delay, hold information in mind, and generate alternative behaviors. Indeed, numerous adult studies have documented the adverse effects of negative emotion on executive processes. Anxiety, for example, impairs inhibition and working memory under stressful conditions (for a review see Eysenck et al., 2007), particularly for temperamentally introverted (Lieberman et al., 2000; Gray, 2001) and anxious children and adults (Calvo et al., 1992; Darke, 1988). Therefore, a second goal of the study was to assess motivational and affective relations to cognition by examining whether longitudinal relations between maternal attention directing behaviors and executive functions vary based on children's temperament type.

In contrast to low temperamental reactivity, behavioral inhibition reflects a lower threshold to novelty (Kagan & Moss, 1962). Because novelty produces high levels of fear in behaviorally inhibited children, they tend to express heightened levels of attentional vigilance and orienting (Martin & Fox, 2006), which may make them more susceptible to interference and distraction. The main regulatory challenge is to overcome their fears and approach a situation they would rather avoid (Derryberry & Tucker, 2006).

Rather than fearing novelty, exuberant children seek it and are characterized as high in approach, activity, reward orientation, and positive affect. Because they experience strong approach motivation and reward appetites, they may be more likely to have difficulties with impulsivity and delay inhibition. However, through volitional control, they may be able to overcome and control heightened reward drives (Derryberry & Tucker, 2006).

Yet, the development and ability to use executive and voluntary processes to regulate reactivity varies, is likely influenced by parenting (Rothbart & Bates, 2006), and may be strengthened and supported by maternal attention-maintaining behaviors in particular. However, little is known about parenting predictors of these long-term executive functions and whether these relations depend upon children's temperament.

The purpose of the present study was to assess relations between maternal attention directing behaviors and delay inhibition and conflict inhibition while assessing differences based on child's temperament type (Putnam & Stifter, 2005). Child temperament was measured at 2 years of age using a variety of tasks designed to elicit approach-inhibition and maternal attention directing behaviors were assessed in a problem-solving task. At 4.5 years of age, several measures of children's delay and conflict inhibition were obtained. Based on past research, it was hypothesized that (1) when focused on the task, maternal attention-maintaining behaviors would predict efficient performance on delay and conflict inhibition, particularly for exuberant children who are more impulsive; (2) when task-focused, maternal-redirection would be associated with children's poorer performance, particularly for inhibited children due to heightened attentional conflict and arousal these behaviors may induce; and (3) when children were not task-focused, maternal redirection would be associated with efficient performance and that this effect would be greatest for exuberant children.

METHOD

Participants

One hundred and fifty infants (78 females) were enrolled at two weeks of age in a study to examine the development of emotion regulation across the first two years of life (follow-ups were conducted at 4, 6, 12 and 13 months of age). At two years of age ($M = 2.01$ years, $SD = .02$), 126 children (63 females) and their parents returned to the laboratory for two visits. A portion of the original sample was re-recruited for a preschool follow-up when children were 4.5 years of age ($M = 4.59$ years, $SD = .13$). Of the original sample, 124 families were located and of these 72 agreed to participate (25 had relocated out of town and 27 declined to participate). Sixty-eight families had complete data for this study.

Participants were drawn from predominantly white, educated, middle class families. Of the original sample, 5 infants were African American, 2 African, 3 Asian, and 1 Native American. At 4.5 year follow-up, all participants were white (34 females). Maternal age at the time of recruitment averaged 29.7 years (range 16 to 43) and maternal education averaged 15.6 years (range 10–26 years). The majority of families reported income between \$50,000 and \$75,000. At 4.5 years, no significant differences were found between participants and non-participants on demographic variables, suggesting that attrition was random. Likewise, no significant differences were found on Time 1 measures (2 year) of child temperament and maternal attention directing behaviors.

Procedures

2 Year Protocol

Temperament Assessment

Procedure: Mother-child and father-child dyads visited the laboratory when the children were 24 and 25 months old, respectively. The majority of each visit was focused on the assessment of toddler approach-inhibition. Tasks were selected based on those used in prior studies to assess behavioral inhibition and stimulation seeking (Fox et al., 2001; Kagan et al., 1984; Park et al., 1997). At both visits, toddlers were 1) introduced to a strange laboratory room; 2) approached by an unfamiliar female; 3) left to play with a “boring” toy; and 4) invited to play “ring around the rosie” with the stranger and parent. Due to time constraints, at the 24-month visit only, toddlers were 1) shown a champagne popper; and 2) exposed to a vacuum cleaner. Electrodes were also placed on the child’s chest to assess sensitivity to novelty and for subsequent heart rate recording. At the 25-month visit, toddlers were also 1) given a choice between high and low intensity toys (e.g., loud or quiet toy buzzer); 2) asked to look in a black box; and 3) asked to jump off a series of steps. Parents were present for all situations but were only actively engaged during ring around the rosie and stranger approach. Details of each of these tasks can be found in Putnam and Stifter (2005).

Coding: Behaviors reflecting approach and inhibition were coded from the videotapes of the two 2 year visits. Proximity to parent was coded using a scale ranging from 1 (clinging) to 5 (two or more steps away from parent) for all episodes listed above except electrode placement and ring around the rosie. Coders gave new ratings if the child increased or decreased proximity to the parent. Reliabilities on 13% of the sample averaged .78 (Cohen’s kappa) and ranged from .68 to 1.00. The number of spontaneous non-distressed vocalizations was coded during all situations with the stranger (reliability on 14% of the data with 83% agreement). Activity level was coded during lab entry, boring toy and play with assistant tasks by applying a scale ranging from 0 (completely still) to 4 (running or

vigorous movement) every 5 seconds (reliability on 14% with an average kappa of .80; range = .59 to .93).

Several episode-specific ratings were made: 1) willingness to allow electrode placement (5-point scale from strongly avoids to no avoidance); 2) willingness to play ring-around-the-rosie game (5-point scale from actively refuses to immediately and enthusiastically joins in); 3) degree of exploration of the black box (6 point scale ranging from no approach to entire head inside box); 4) willingness to jump from steps (7 point scale ranging from no approach to jumps off prior to prompts); and 5) off task behavior during the presence of the boring toy (coded every 5 seconds with a 3-point scale ranging from no off-task behavior to active engagement in off-task behavior). Finally, latencies to choose a low or high intensity toy were scored. If the child did not choose a toy, they were assigned a latency score of 20 seconds. Reliability was computed on 14% of the sample for the above ratings and Cohen's kappas ranged from .80 to .85. Latency scores within two seconds were reliable with 93% agreement.

Positive-Negative affect: Facial and vocal expressions of positive affect and negative affect were rated from the videotapes using a global scale ranging from 0 (no affect) to 5 (continuous, high intensity affect). Reliability was calculated on 11% of the visits with kappas at .71 for positive affect and .73 for negative affect.

Temperament group formation: All the measures from the 24–25 month visit (33 total behaviors) were subjected to a Confirmatory Factor Analysis which supported a three factor model (Putnam & Stifter, 2005) consisting of positive affect, negative affect, and approach-inhibition. A hierarchical cluster analysis (Ward's method) and examination of dendograms suggested a 4-cluster solution. K-means were calculated to assign children to groups. K-means is a method of cluster analysis that divides observations into k clusters and assigns observations to clusters based on the nearest mean (Afifi & Clark, 1990). The four groups consisted of: 1) a group that was extremely high in negativity and low in approach (extremely inhibited), 2) a group that was high in positive affect and approach (exuberant), 3) a group that was low on both positive and negative affect and moderate on approach-inhibition (low reactive) and 4) a group similar to Cluster 1 but less extreme (inhibited). Due to the low number in the extremely inhibited group ($n=3$), it was combined with the inhibited group to become the new inhibited temperament group. Of the children in the 4.5 year sample, 15 children had been classified as earlier as inhibited, 22 as low reactive, and 31 as exuberant. Gender was approximately, equally distributed across groups. Please refer to Putnam and Stifter (2005) for more information.

Maternal attention directing behaviors

Procedure: At the 24 month visits, each mother-child dyad participated in a 3 minute structured problem solving task that involved building a figure made of Lego pieces. Mothers and their children sat at a child-sized table with a bucket of Lego pieces and a paper template of the figure to be built. Interactions were videotaped and subsequently coded for maternal redirection of child attention, maternal maintenance of child attention, and on- and off-task child behavior.

Coding-Data reduction: Maternal *attention-maintaining* was operationalized as verbal or non-verbal behaviors which served to support, encourage or maintain the child's current focus of attention on the problem solving task. Verbal behaviors included asking questions, commenting, describing the task, or giving praise, whereas non-verbal maternal behaviors included pointing toward the child's current focus of attention. Behaviors were coded in five-second intervals. The average inter-reliability Kappa coefficient for maternal

maintaining was .82 on 15% of the data. The proportion of time (in seconds) that mothers maintained their child's attention while (s)he was on task for each mother was used in all analyses. Log and squared transformations were used to correct for negative skewness in maternal proportion scores.

Maternal *attention-redirecting* behaviors were coded from videotape and included verbal or non-verbal behaviors which served to redirect the child away from their current focus of attention back to or toward another aspect of the problem solving task. To examine relations based on context, these maternal behaviors were coded (1) when the child was focused on the task (child on-task), and (2) when the child was not attempting to accomplish the goals of the task such as walking off or looking at other objects in the room (child off-task). Verbal behaviors included asking questions, commenting, describing the task, or giving directives, whereas non-verbal maternal behaviors included pointing or giving the child a task object shifting their attention away from their focus. In both contexts, behaviors were coded in five-second intervals using a computer program. The average kappa coefficient for maternal attention directing on 15% of the data was .90. Proportion scores were calculated for each mother reflecting the amount of time mothers redirected their child's attention when (s)he was (1) on task, and (2) off task. Log transformations were used to correct for negative skewness in all proportion scores and were used in subsequent analyses.

4.5-Year Protocol—At 4.5 years of age, children participated in several tasks designed to assess emotion regulation, moral behavior, parent-child interaction, and executive function. Only the delay inhibition tasks (delay of gratification and dinky toys) and conflict inhibition tasks (three pegs, day-night, tapping) were used in the present study and are detailed below. All procedures were administered at a child-sized table and videotaped for off-line coding. The parent was in the room during the majority of all tasks unless otherwise noted.

Delay inhibition

Procedure: Two tasks were used as measures of delay inhibition – delay of gratification and “dinky toys.” The delay of gratification task was taken from Mischel's classic design (Mischel & Ebbesen, 1970) in which children are given the choice between two chocolate candies if they wait or one if they are not able to wait a set amount of time. Children were told the rules and then given a bell to ring if they could not wait. They were left alone in the room for a maximum of 15 minutes. If the child rang the bell before that time, the experimenter returned and the child received one piece of candy. If they did not ring the bell, the experimenter returned after 15 minutes and the child was given the two pieces of candies. Latency to wait to ring the bell on the delay of gratification task was coded from the videotapes and calculated using a computer program. Children who waited the entire 15 minutes of the delay of gratification task were given a latency score of 900 seconds.

In the dinky toys task (adapted from Goldsmith et al., 1995) a clear, lidded container of small toys was presented to the child. The child was told that (s)he could have one of the toys but should look carefully because once chosen (s)he could not return the toy for another. The lid was removed and the child was allowed to look and choose but if (s)he touched a toy, that toy was considered to be the choice. Latency to choose a dinky toy was coded from the videotapes and calculated using a computer program.

Conflict inhibition

Procedure: Three tasks designed to assess the child's ability to maintain rules in mind while inhibiting a pre-potent response and executing a conflicting novel response were administered (Carlson & Moses, 2001). The Three Pegs task required the child to tap colored pegs according to the experimenter's instructions (Balamore & Wozniak, 1984). A

wooden board with three different-colored pegs, ordered red-yellow-green, was presented by the experimenter. A pretest insuring that the child understood the colors was conducted followed by a verbal instruction to the child to tap the pegs in the order – red, green, yellow. The task captures conflict inhibition by requiring children to (1) hold in mind the appropriate sequence for tapping pegs on the board (e.g., red-yellow-green), (2) inhibit the prepotent sequence (e.g., order in which the pegs are presented on the board; red-yellow-green), and (3) generate the appropriate response (e.g., red-green-yellow). If the child tapped correctly, a second trial was conducted. If the child tapped incorrectly, then the experimenter demonstrated the task and asked the child to tap the pegs. If the child was correct a second trial was conducted. If incorrect, the child received a third demonstration and was asked to tap the pegs for two trials. Because the three pegs task was scored as either pass or fail but had several instruction trials, children were given a “0” if they failed the task, “1” if they required two repeated instructions, “2” if they required one additional instruction, and “3” if they performed the task after the first demonstration. Scores consisted of the number of trials required to pass the task (reverse-scored), ranging from 0 (i.e., failed the task) to 3 (i.e., passed the task on the first attempt).

The Day-Night task is a Stroop-like task (Gerstadt, Hong & Diamond, 1994) utilizing a set of cards containing black cards with a picture of a moon (50% trials) and white cards with a picture of a sun (50% trials). When children saw the black card they were instructed to say “day” and when they saw the white card they were instructed to say “night.” Two practice trials were administered and repeated if incorrect. Sixteen test trials fixed random order followed. Following Carlson and Moses (2001), final scores consisted of percent correct trials and the number of practice trials required (reverse-scored). Dependent measures were standardized and averaged to create a single composite day-night score.

The Tapping task (Diamond & Taylor, 1996) required the child to learn and apply two rules. When the experimenter tapped the table with a stick once, the child was to tap the table twice (50% trials), and when the experimenter tapped the table twice the child was to tap the table once (50% trials). If the child performed both rules without a prompt, test trials began. If the child responded incorrectly, the rules were re-demonstrated and 16 test trials were administered in a fixed random order. Final scores consisted of the percent correct trials and the number of practice trials required (reverse-scored). Dependent measures were standardized and averaged to create a single tapping task composite.

Tasks were administered in the following order: (1) three pegs, (2) day-night stroop, (3) delay of gratification, (4) tapping task, and (5) dinky toys. Based on Carlson and Moses’ finding (2001) and to confirm the two components of executive function, a principal components analysis was conducted on the delay gratification, dinky toys, day-night, tapping, and three pegs measures. As expected, two components emerged after rotation reflecting conflict (eigenvalue = 1.7) and delay inhibition (eigenvalue = 1.1). Day-night (.66), tapping (.84), and three pegs (.53) scores loaded on the first component, whereas delay of gratification (.46) and dinky toys (.88) loaded on the second. A composite score representing delay inhibition was calculated by averaging the z-scores of the two latency variables. A conflict inhibition composite was created by averaging the z-scores of day-night, tapping and three pegs tasks.

RESULTS

Tables 1 and 2 present descriptive statistics. No significant differences were found between temperament groups and gender on study variables. Pearson correlations were computed to test for relations among the maternal attention measures. Maternal attention-maintaining was negatively associated with maternal attention- redirection when the child was on task ($r = -. .$

43, $p < .001$). Table 3 presents correlations between variables used in analyses by temperament group.

Primary Analyses

To test the main effects and interactions of maternal attention directing behavior and temperament style in the prediction of executive functions, multiple regression analyses were performed. Dummy groups were created with the inhibited group as the reference. Separate analyses were conducted to assess the interactions between temperament and maternal behavior (maternal attention- maintaining, attention- redirection-child on task and attention-redirection- child off task) on conflict inhibition and delay inhibition. Temperament groups were entered first, followed by centered maternal behavior based on subtracting the group mean from each score. Finally, interactions between temperament groups and centered maternal behavior variables were created and entered into the model. All analyses were conducted on the restricted (main effects only) and full (main effects and interactions) models. Overall, F values reflect the significant difference between the restricted and full restricted models. In other words, significant F change values indicate whether the model including the interaction terms (full model) was significantly different than models without the interaction terms (restricted model), and whether the added increment towards explaining the overall R^2 was significant. With the inhibited group as the reference, the intercept represents the mean of the inhibited group, and the regression coefficient for the low reactive group represents the difference in the means between the inhibited and low reactive groups. The regression coefficient for the exuberant group represents the difference in the means between the inhibited and the low reactive groups, while the regression for the moderator (e.g., mean of the inhibited group) reflects whether the intercept depends upon the value of the moderator. Finally, the interactions reflect whether the difference between the groups reflects the moderator. Specifically, these t-values provide tests of betas for the significant interactions (e.g., specific contrasts between temperament groups such as 'low reactive versus inhibited' and 'exuberant versus inhibited'). Post-hoc probing was conducted to interpret interactions only for models yielding a significant change in R^2 with the inclusion of interaction terms (Cohen, Cohen, West, & Aiken, 2003). To probe interactions, regression equations were restructured to reflect the regression of the criterion on one predictor and simple slope regressions were plotted to display the interactions at the mean and one standard deviation above and below the mean (see Aiken & West, 1991).

Results of regression models predicting delay and conflict inhibition are reported below. Within each section, the results of models assessing interactions between temperament style and maternal attention behavior are presented in the following order: attention-maintaining, attention-redirection-child off task, and attention-redirection-child on task.

Delay Inhibition

Attention-maintaining: Regression analysis with delay inhibition as the dependent variable and maternal attention-maintaining and temperament group as the predictors revealed no significant main or interaction effects.

Attention-redirection-child on-task: Regression analysis with delay inhibition as the dependent variable and maternal attention-redirection when the child was on-task, temperamental style, and interactions as predictors can be found in Table 4. The inclusion of interaction terms in the model revealed a significant change in R^2 with 15% of the variance explained, $F(2, 60) = 3.95$, $p < .05$. While there was a significant main effect for maternal attention- redirection-child on-task, $t(65) = -2.93$, $p < .01$, this was subsumed under significant temperament x maternal attention- redirection interactions-child on-task.

Significant interactions were found for contrasts comparing low reactive versus inhibited and exuberant versus inhibited groups, respectively, $t(65) = 2.81, p < .01$, $t(65) = 2.32, p < .05$. These interactions indicated that the difference between groups depended upon the moderator. To probe the interactions, we plotted the interactions and tested for significant slopes. Figure 1 illustrates the interaction between temperament group and maternal attention-redirection for delay inhibition. A test of simple slopes revealed that maternal attention-redirection when the child was on task predicted poorer delay inhibition for the inhibited ($B = -1.51, p < .01$), but not exuberant ($B = -.11, ns$) and low reactive temperament groups ($B = -.01, ns$).

Attention- redirection-child off-task: No significant main effects or interactions were noted in the prediction of delay inhibition based on maternal attention-redirection when the child was off task and child temperament.

Conflict Inhibition

Attention-maintaining: Regression analysis with conflict inhibition as the dependent variable and maternal attention-maintaining, temperamental style, and interactions can be found in Table 5. The inclusion of interaction terms in the model revealed a significant change in R^2 with 20% of the variance explained, $F(2, 60) = 5.25, p < .01$. While there was a significant main effect for maternal attention-maintaining, $t(65) = 2.29, p < .05$, this was subsumed under a significant temperament x maternal attention-maintaining interaction, $t(65) = -2.61, p < .01$. A significant interaction was found for the contrasts comparing low reactive versus inhibited groups, indicating that the difference between groups depended upon the moderator. To probe the interaction, we plotted the interaction and tested for significant slopes. Figure 2 illustrates the interaction between temperament group and maternal attention-maintaining for conflict inhibition. A test of simple slopes revealed that maternal attention-maintaining of child focus during toddlerhood predicted better conflict inhibition for the inhibited ($B = .51, p < .05$) and exuberant temperament groups ($B = .56, p < .05$), but not the low reactive group ($B = -.22, ns$).

Attention-redirection-child on- task: The results of a regression analysis with conflict inhibition as the dependent variable and maternal attention-redirection when the child was on-task, temperamental style, and interactions can be found in Table 5. The inclusion of interaction terms in the model revealed a significant change in R^2 with 16% of the variance explained, $F(2, 60) = 4.14, p < .05$. While there was a significant main effect for maternal attention-redirection while the child was on-task, $t(65) = -2.40, p < .05$, this was subsumed under a significant temperament x maternal attention-redirection-child on-task interaction, $t(65) = 2.47, p < .01$. A significant interaction was found for the contrasts comparing low reactive versus inhibited groups, indicating that the difference between groups depended upon the moderator. To probe the interaction, we plotted the interaction and tested for significant slopes. Figure 3 illustrates the interaction between temperament group and maternal attention-redirection for conflict inhibition. A test of simple slopes revealed that when mothers increased their redirection of their toddlers' attention while the toddlers were on-task conflict inhibition decreased for the inhibited ($B = -1.23, p < .05$), but not exuberant ($B = -.50, ns$) and low reactive children ($B = .08, ns$).

Attention-redirection-child off- task: No significant main effects or interactions were noted in the prediction of conflict inhibition based on maternal behavior when the child was off task and child temperament.

DISCUSSION

Despite the proliferation of research on the development of executive function, most has focused on individual factors with considerably less on early social and child antecedents. Here we have demonstrated that maternal attention directing behaviors and child temperament type during toddlerhood interact to predict executive function processes during preschool. Specifically, we found that maternal attention-maintaining was associated with high levels of conflict inhibition for inhibited and exuberant children, whereas attention-redirecting was associated with low levels of delay and conflict inhibition for inhibited children. These findings demonstrate that social processes such as maternal attention-directing behaviors along with child temperament predict preschool executive function, but that effects vary based on the executive process assessed. And while recent studies have documented positive relations between parental support or maintenance of children's focus of attention and competent executive processing skills such as goal planning and cognitive flexibility (Landry et al., 2000), this is the first study to move beyond cross-sectional studies to examine this longitudinally with respect to children's observed temperament type.

The present findings are consistent with those documenting positive relations between maternal attention maintaining and children's cognition such as focused attention (Bono & Stifter, 2003), object exploration (Landry et al., 1996), language skills (Barnes, Gutfreund, Satterly, & Wells, 1983), and independent problem-solving (Landry et al., 2000). In a study conducted by Gauvain & Fagot (1995), the joint contribution of maternal perceptions of toddler temperament and maternal behavior were examined during a problem-solving task. Results from this study revealed that children who assumed more responsibility and involvement in the task performed better if their mothers perceived them as having an easy temperament. Conversely, children whose mothers assumed more responsibility for completing the challenging aspects of the task performed worse if their mothers rated them as difficult. By examining more specific parenting behaviors along with observations of children's temperament type on long-term executive processes, our results demonstrate that maternal attention maintaining behaviors longitudinally predicted better conflict inhibition but only for inhibited and exuberant children.

Why would maternal attention maintaining predict increased conflict but not delay inhibition for inhibited and exuberant children? To address this we turn to findings on the development of executive functions and the role of affect on executive functions. First, there has been considerable evidence documenting differences in the early development of delay and conflict inhibition. By 4 years of age, most children evidence competence in delay inhibition, whereas conflict inhibition is often achieved later by 5- or 6-years of age (Carlson, 2005). Conflict inhibition depends upon the achievement and coordinated integration of three executive processes—delay inhibition, working memory, and activation control, rendering it more developmentally complex. And like delay inhibition, increases in working memory abilities have been related to development in attention systems (Espy & Bull, 2005). Therefore, maternal attention maintaining may be particularly instrumental in facilitating the development of conflict inhibition by enhancing the development of underlying competencies such as attention focusing needed to integrate and coordinate multiple executive processes. Conversely, because delay inhibition is typically achieved by age 4, maternal attention maintenance may not be as critical at this age for the development of delay inhibition as it is for conflict inhibition. Indeed, sixty-five percent of the sample was at ceiling on the delay of gratification task, suggesting that many had achieved delay inhibition by 4 ½ years of age. Therefore, it is possible that the effects of maternal maintaining on this ability may be most pronounced at earlier ages.

Second, the results of the present study demonstrate that maternal maintaining predicts complex executive processes such as conflict inhibition for children who are prone to be highly reactive in novel situations (both inhibited and exuberant) but not low reactive children. Discomfort and over-excitement in the face of novelty may influence cognitive development by affecting the acquisition of information from new experiences (Bates, 1989). Both inhibited and exuberant children are prone to experience heightened arousal and either fear or exuberance, respectively, which may impede their cognitive and attentional processing (Rothbart & Bates, 2006). The high fear or reward tendencies, characteristic of these temperamental styles, may render them sensitive to distractions and conflict with the ability to focus attention or hold information in mind. Indeed, like fearful children, children high on approach have also been found to have lower levels of performance on working memory and conflict inhibition tasks (Davis, Bruce, & Gunnar, 2002; Wolfe & Bell, 2007).

Maternal behaviors that maintain children's attentional focus may help attenuate high levels of temperamental reactivity. This type of support may allow children to focus and organize responses and strengthen developing volitional control in the face of competing distractions such as other objects and or emotional arousal. Previous research has documented that sensitive behaviors directed towards inhibited children that are firm, but not over-solicitous or overwhelming, are associated with internalization and buffer against poor social outcomes (Kochanska, 1991; Rubin et al., 2002). Finally, maternal attention maintaining behaviors may be particularly relevant to the development of conflict inhibition due to the high working memory demand. On the other hand, our findings revealed that redirecting children's attention away from the task may have negative implications for executive function.

Redirecting attention away from the task while the child was on-task appears to be particularly problematic for inhibited children as our results showed this maternal behavior to be related to poorer performance on both delay and conflict inhibition for these children only. Rather than encouraging or strengthening children's attention focus, maternal attention redirection requires children to disengage, shift, and refocus his or her attention on something that is not of current interest to the child, but is of interest to the parent (Bono & Stifter, 2003). This requires greater allocation of attentional resources and consequently may overload the child's developing executive abilities by producing attentional conflict and interference in the inhibited child's already aroused system. In sum, this may result in a stressful context for inhibited children as they try to attend to task demands potentially mirroring findings of anxiety compromising both inhibition and working memory (Calvo et al., 1992; Darke, 1988; Eysenck et al., 2007; Ladouceur et al., 2009).

Indeed, robust findings indicate that fear and anxiety compromises inhibition processes in adults, particularly under stressful conditions (for a review see Eysenck et al., 2007). Therefore, it is possible that for temperamentally inhibited children, maternal attention redirection during problem-solving may produce a stressful context that intensifies temperamental fear reactivity and reduces inhibition efficacy. This may explain why maternal attention redirection predicts reduced efficiency in both delay and conflict inhibition but only for temperamentally inhibited children. Likewise, given the greater sophistication needed to demonstrate effective conflict inhibition, it is possible that attempts to redirect children's attention away from task demands may compromise developing working memory, and the integration and coordination of working memory with delay necessary to perform these conflict tasks. As inhibited children tend toward greater sensitivity in novel situations, when mothers engage in maternal attention redirecting, this may heighten children's arousal and produce emotional interference effects such as those noted by Rubin and colleagues (2002); inhibited children whose mothers were more intrusive evidenced significantly higher levels of emotion dysregulation compared to peers.

Therefore, for inhibited children, while maternal attention-maintaining may support the development of attention focusing and volitional control, attention-redirecting when focused on task goals, may weaken it.

Interestingly, maternal redirection when the inhibited children were off-task was not related to executive processes. It is possible that, when children are off-task, maternal attention redirection may not be as stressful or intrusive compared to when children are on-task. Therefore, the context in which maternal attention redirection occurs may be a critical determinant of its impact and how it may be experienced. When an inhibited child is on-task, for example, it may exacerbate pre-existing levels of fear of novelty and reactivity, whereas when the child is off-task, it may pull for compliance. Thus, contexts of maternal attention redirection may yield distinct affective contexts depending upon whether the child is on or off-task and depending upon the child's temperamental style. These distinct affective contexts may render differential effects of motivational and temperamental influences on the development of executive functions and may account for why temperamental style did not moderate relations between maternal attention redirection executive processes when children were off-task. Yet, these results could also be driven by the lower probability of maternal attention direction versus maternal attention maintaining and child on-task versus off-task behavior occurring in this particular mother-child problem-solving context. Future research is needed to explore maternal attention direction when children are off-task in diverse and potentially more stimulating and distracting problem-solving contexts.

It is also possible that temperamentally inhibited children, who are reactive to novelty, may perform worse on inhibition tasks when their mothers engaged in attention redirecting, because the lack of support for their current focus of attention weakens their developing activation control. The ability to inhibit impulses (inhibitory control) has been differentiated from the ability to voluntarily execute behaviors (activation control) (Carlson & Moses, 2001; Derryberry & Rothbart, 1988). Activation control may be most challenging for temperamentally inhibited children who must override the tendency to withdraw in order to perform a novel task. Indeed, Eisenberg and colleagues (1995) reported that shy students had significantly lower levels of activation control and suggested that the ability to initiate action rather than inhibit ongoing behavior may be more difficult for inhibited or shy individuals. Yet significantly less attention has been given to understanding this component of conflict inhibition. Our data suggest that for temperamentally inhibited children, maternal attention redirection may tax the development of underlying competencies such as attentional focus, working memory, activation control or their integration. Further research is needed to elucidate the mediators of these moderating effects (Bates & Pettit, 2007).

Conversely, maternal attention-redirecting was not associated with conflict inhibition for exuberant children and may be due to different temperamental propensities. For example, negative affect (e.g., worry, shyness) has been associated with reduced attentional control, working memory capacity, and low activation control, whereas positive affect, characteristic of exuberant children to novelty, has not (Eysenck, Derakshan, Santos, & Calvo, 1997; Haynes, Hirsch, & Matthews, 2008). Differential emotion-cognition interactions (e.g., positive versus negative reactivity) during joint problem solving tasks and may account for the lack of interaction between maternal attention redirection and conflict inhibition for exuberant children. However, more research is needed to assess these developing relations by temperament type.

The present study has several limitations. Participants in our sample were Caucasian and highly educated, limiting generalizability. Moreover, although the longitudinal design contributes to our understanding of precursors of executive function and behavioral control,

sample attrition due to the length of time between temperament assessments and outcomes (2.5 years) and the lack of multiple assessments over time, limits our ability to interpret causal relations across time. Further research is needed to rule out and examine relations between other maternal, child, and dyadic antecedents of executive processes (e.g., contingent responsiveness), as well as more distal factors such as socioeconomic status (e.g., Hughes & Ensor, 2009). Dyadic system analyses of the co-construction of executive processes (for example see Putnam & Stifter, 2002) will also allow for a more detailed understanding of factors that contribute to the development of executive processes, as well as provide opportunities to test recent developmental social cognitive theoretical models of executive processes (e.g., Lewis, Carpendale, Towse, & Maridak-Kassotaki, in press).

As proposed by Vygotsky (1978), during socially mediated joint activity, a context is created where qualitatively higher forms of alternative and volitional strategies can develop. Our findings support relations between social processes and executive function by demonstrating that maternal attention directing behavior appears to be an important factor in the relation between temperamental style and executive function, particularly for inhibited and exuberant toddlers, who when focused on task demands, demonstrate significantly better executive function. On the other hand, redirecting inhibited children's attention when they are task focused is associated with poorer executive skills. These findings underscore the importance of social processes on the development of executive function and highlight the need to examine relations within context.

Acknowledgments

This research was supported by a grant from the National Institute of Mental Health (MH 50843) to CAS and a fellowship awarded to AMC (T32 MH 070327). We thank the families who participated in the Emotional Beginnings Project.

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Figure 1. Maternal attention-redirected-child on task predicts low delay inhibition for inhibited children.

Figure 2. Maternal attention-maintaining predicts high conflict inhibition for inhibited and exuberant children.

Figure 3. Maternal attention-redirecton-child on task predicts low conflict inhibition for inhibited children.

Table 1

Means and Standard Deviation for the Study Variables by Temperament Group

Measure	Inhibited (n = 15)	Exuberant (n = 31)	Low Reactive (n = 22)
Maternal Attention-maintaining ^a	0.82 (0.25)	0.85 (0.23)	0.84 (0.20)
Maternal Attention-redirection (child on task) ^a	0.12 (0.15)	0.23 (0.41)	0.14 (0.21)
Maternal Attention-redirection (child off task) ^b	0.01 (0.02)	0.01 (0.04)	0.00 (0.00)
Child Off-Task ^c	18.6 (25.00)	23.43 (34.95)	14.13 (22.45)
Delay Inhibition ^d	0.28 (1.16)	-0.04 (1.06)	-0.14 (0.76)
Conflict Inhibition ^e	-0.34 (1.04)	0.15 (0.84)	0.01 (1.15)

Note:

^aMaternal behavior as proportion of time child on task.^bMaternal behavior as a proportion of time child off task.^cProportion of child off-task.^dDelay inhibition composite reflects the average of the two z-scores for behavioral control measures- delay of gratification and dinky toys.^eConflict inhibition composite consists of the average of the three z-scores for executive function measures- day-night, tapping, and three pegs.

Table 2

Means and Standard Deviations of Executive Function Measures (n=68)

Measure	Mean(standard deviation)
Delay Tasks	
Latency to delay of gratification	659.05 (355.61)
Latency to choose dinky toy	27.52 (43.31)
Day-Night Task	
Number of practice trials required	2.67 (0.87)
Percent correct across the entire task	0.50 (0.19)
Tapping Task	
Number of practice trials required	3.55 (1.17)
Percent correct across the entire task	0.72 (0.26)
Three-Pegs Task	
Average number of conditions required to pass	1.79 (1.17)

Table 3

Correlations Between Maternal Behaviors and Executive Function Variables by Temperament Group

(a) Inhibited Group (n=15)

Measure	1	2	3	4
1. Maternal Maintaining				
2. Maternal Redirection	-.88 ***			
3. Delay Inhibition	.47	-.65 **		
4. Conflict Inhibition	.54 *	-.58 *	.43 +	

(b) Exuberant Group (n=31)

Measure	1	2	3	4
1. Maternal Maintaining				
2. Maternal Redirection	-.31 +			
3. Delay Inhibition	.11	-.02		
4. Conflict Inhibition	-.26	.12	.22	

(c) Low Reactive Group (n=22)

Measure	1	2	3	4
1. Maternal Maintaining				
2. Maternal Redirection	-.53 **			
3. Delay Inhibition	-.24	-.10		
4. Conflict Inhibition	.39 +	-.32	.03	

Note:

+ p < .10;

* p < .05;

** p < .01;

*** p < .001.

Table 4

Regression Analysis of Maternal Attention Redirection Behaviors-Child On-Task and Temperament on Delay Inhibition.

	B	SE (B)	β	Increment to R ²
I. Maternal Redirection (MAR)				
Restricted Model				0.04
Low Reactive	-0.29	0.32	-0.14	
Exuberant	-0.42	0.34	-0.19	
MAR	-0.35	0.40	-0.11	
Full Model				0.11 [*]
Low Reactive	-0.22	0.31	-0.11	
Exuberant	-0.32	0.33	-0.15	
MAR	-4.83	1.64	-1.52 ^{**}	
Low Reactive versus Inhibited	4.79	1.70	1.34 ^{**}	
Exuberant versus Inhibited	4.47	1.92	0.54 [*]	

Note:

⁺ p < .10;

^{*} p < .05;

^{**} p < .01;

^{***} p < .001.

Table 5

Regression Analysis of Maternal Attention Maintaining and Redirection-Child On-Task Behaviors and Temperament on Conflict Inhibition.

	B	SE (B)	β	Increment to R^2
I. Maternal Maintaining (MAM)				
Restricted Model				0.06
Low Reactive	0.45	0.31	0.22	
Exuberant	0.28	0.34	0.13	
MAM	0.74	0.54	0.17	
Full Model				0.14 **
Low Reactive	0.43	0.29	0.22	
Exuberant	0.23	0.31	0.11	
MAM	2.25	0.98	0.51 *	
Low Reactive versus Inhibited	-3.19	1.22	-0.51 **	
Exuberant versus Inhibited	0.18	1.41	0.02	
II. Maternal Redirection (MAR)				
Restricted Model				0.04
Low Reactive	0.50	0.32	0.25	
Exuberant	0.31	0.34	0.15	
MAR	-0.25	0.39	-0.08	
Full Model				0.12 *
Low Reactive	0.53	0.31	0.27	
Exuberant	0.39	0.32	0.18	
MAR	-3.89	1.62	-1.23 *	
Low Reactive versus Inhibited	4.14	1.68	1.17 **	
Exuberant versus Inhibited	2.30	1.90	0.28	

Note:

⁺ $p < .10$;

* $p < .05$;

** $p < .01$;

*** $p < .001$.