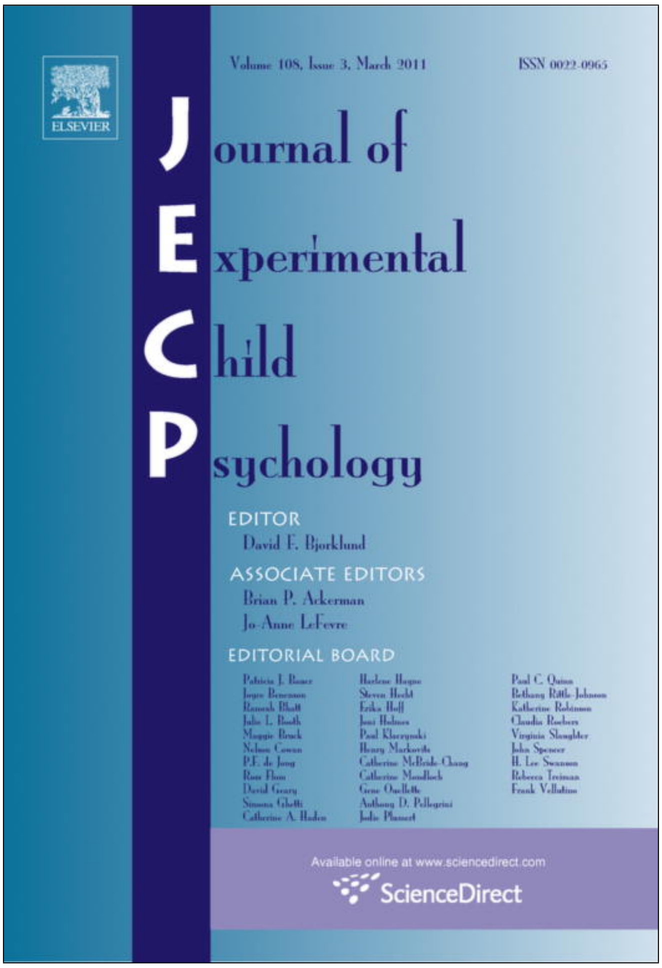
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Sustained attention and age predict inhibitory control during early childhood

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ABSTRACT

Executive functioning skills develop rapidly during early childhood. Recent research has focused on specifying this development, particularly predictors of executive functioning skills. Here we focus on sustained attention as a predictor of inhibitory control, one key executive functioning component. Although sustained attention and inhibitory control have been linked in older children and adults, these links have not been well specified during early childhood. The current study examined both parent-rated and laboratory measures of sustained attention as predictors of both parent-rated and laboratory measures of inhibitory control among 3- to 6-year-olds. As expected, children with higher sustained attention abilities exhibited greater inhibitory control. Moreover, inhibitory control increased across age. These findings reveal important details about the development of sustained attention and inhibitory control during early childhood.

Introduction

Executive function is a broad theoretical construct that includes the ability to control and direct one's mental abilities to complete a task or reach a goal. Many researchers conceptualize executive function as including components such as inhibitory control, planning, and set shifting (Hughes, 1998; Welsh, Pennington, & Groisser, 1991; Zelazo, Carter, Reznick, & Frye, 1997). One way to understand this complex construct is to probe its components and their development in greater detail, focusing particularly on predictors of executive functioning skills. Research with preschool-aged

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children is important because of the rapid development of executive functioning during early childhood (Carlson, 2005; Espy, 1997) and because executive functioning skills are strongly related to school readiness (Blair & Razza, 2007; McClelland et al., 2007). The goal of this investigation was to specify the extent to which sustained attention serves as a predictor of inhibitory control (a key executive functioning component) throughout early childhood.

Recently, Hughes (1998) completed a factor analysis of executive functioning during the preschool years, yielding three central aspects: inhibitory control, attentional flexibility, and working memory. These factors are remarkably similar to those evident with other tasks and age groups (Garon, Bryson, & Smith, 2008; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000), lending support to this compositional account. The construct of inhibitory control is particularly important. In fact, disinhibition has been linked with a variety of difficulties across academic and social domains (Blair & Razza, 2007; Olson, 1989) as well as with childhood disorders (Barkley, 1997).

Adopting a componential view of executive functioning, we focused on the development of inhibitory control here. In particular, we probed whether sustained attention predicts inhibitory control across the preschool years. According to Garon and colleagues (2008), the development of attention provides the foundation for developmental gains in all other executive function components during the preschool years. Similarly, recent theoretical accounts of attention propose profound roles for executive attention and its development during infancy and early childhood (Rothbart & Posner, 2001). Indeed, sustained attention and disinhibition have been linked empirically during infancy and toddlerhood (Kochanska, Murray, & Harlan, 2000) as well as during the school years and adulthood (Barkley, 1997; Berlin, Bohlin, & Rydell, 2003). Nonetheless, very few studies have examined the predictive relation between sustained attention and inhibitory control in preschool-aged children (Hrabok, Kerns, & Müller, 2007). We contend that it is essential to specify this relation precisely during the preschool years.

Inhibitory control is a complex construct with many aspects. For temperament researchers, the construct includes the ability to plan and to suppress inappropriate action (Rothbart, Ahadi, & Evans, 2002). Similarly, for executive function researchers, inhibitory control is characterized as the ability to engage in an appropriate response instead of a more probable, but less appropriate, response (Carlson, 2005). This may involve the suppression of a dominant response while a subdominant response is activated. Cognitive aspects of inhibitory control also have been identified. In particular, cognitive flexibility enables children to shift perspectives, thought patterns, or foci of attention (Diamond, 2006). Delaying of responses and slowing of motor activity are other important aspects of inhibitory control (Murray & Kochanska, 2002).

Children exhibit dramatic gains in inhibitory control during early childhood (Carlson, 2005). Often laboratory measures are included in conjunction with parent- or teacher-report measures of inhibitory control. In some cases, findings yield consistency across measurements (Kochanska, Murray, Jacques, Koenig, & Vandergeest, 1996). In other cases, findings diverge, perhaps because parent-report measures assess general impressions of executive functioning in everyday contexts, whereas laboratory measures assess specific aspects of executive functioning (Bodnar, Prahme, Cutting, Denckla, & Mahone, 2007; Liebermann, Giesbrecht, & Müller, 2007). In this study, we used both laboratory tasks (selected from recommendations in Carlson, 2005) and parent ratings to specify developmental increases in inhibitory control during early childhood.

According to Posner and Peterson's (1990) classic model, sustained attention is the ability to maintain focus continuously on specific stimuli. Perhaps the most important aspect of sustained attention is the ability to direct and control one's attention endogenously. Developmental increases in this endogenous, anterior attention system during early childhood are well established (Colombo, 2001; Ruff & Capozzoli, 2003). One such change is the ability to sustain focused attention for longer periods of time, evident in a variety of contexts during the toddler and preschool years (Corkum, Byrne, & Ellsworth, 1995; Kannass & Oakes, 2008). For adults and older children, sustained attention often has been studied using methodologies that test the ability to detect targets in long sequences of irrelevant distractors (Conners, 2000). Typically, performance is evaluated in terms of errors of commission (responding to distractor stimuli) and omission (missing target stimuli). Recently, a similar cancellation task was developed for preschoolers (Byrne, Bawden, DeWolfe, & Beattie, 1998; Corkum et al., 1995; DeWolfe, Byrne, & Bawden, 1999).

The main purpose of this study was to specify how sustained attention and age predicted inhibitory control to further our understanding of the development of executive functioning skills during early childhood. This study examined both observational and parent-rated measures of inhibitory control using well-established laboratory tasks (Bear/Dragon, Whisper, Day/Night, and Gift Delay) and a parent rating scale (Inhibitory Control subscale from the Child Behavior Questionnaire [CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2000] short form [Putnam & Rothbart, 2006]). In addition, an observational measure of sustained attention (Picture Deletion Task for Preschoolers–Revised [PDTP-R; Byrne et al., 1998]) and parent-rated measures of sustained attention problems were included. Specifically, several subscales from popular rating scales (Attention Problems and Executive Functioning subscale from the Behavioral Assessment for Children, Second Edition [BASC-2; Reynolds & Kamphaus, 2004] and Attentional Focusing subscale from the CBQ) were used to create an attention problems composite score that allowed us to demonstrate the extent to which the observational and parent-rated measures of sustained attention show similar predictive patterns.

Method

Participants were 103 children (46 boys and 57 girls) between 3 and 6 years of age (M = 61.24 months, SD = 14.60) and one parent per child. Most children were White and from middle- to upper middle-class families. None reported significant medical impairments or developmental delays. Data from a small number of participants were omitted from individual analyses due to children's refusal to complete a task, experimenter error, or missing parent-report data.

The tasks were administered in one of five orders using a partial Latin square design. The Gift Delay task was always administered at the end of the session because it included a wrapped gift. All sessions were video-recorded for coding purposes.

Sustained attention

The PDTP-R instrument (Byrne et al., 1998) was used to measure sustained attention. The shape task was used for training. One double-sided sheet of paper contained a picture of the target item (triangle) at the top and 15 targets and 45 distractors (circles, octagons, and squares) in the larger array on each side of the page. The main cat task followed. This task contained four double-sided pages of cats. The target cat, standing with its tail in the air, was presented at the top of each page, outlined by a green square, and there were 60 additional cats on each side of each page: 15 target cats and 45 distractor cats (cats sitting up straight, sitting sideways, lying down, or pouncing).

Children first completed a training phase to ensure that they understood the task. They were given an opportunity to use the self-inking stamper. Then the researcher explained the shape task. Children were instructed to mark the shapes on the page that were "just the same" as the outlined example at the top of the page. Following two pages of the shapes task, children reviewed their work with the researcher. Then children moved on to the eight-page test phase in which they were asked to mark occurrences of the target cat as fast as they could. Errors of omission and commission in the cat task were coded. Interrater reliability was assessed for 20 sessions (20% of the sample) using intraclass correlations, revealing coefficients of 1.0 for omissions and .99 for commissions.

Inhibitory control tasks

Bear/dragon

Two hand puppets, a bear and a dragon, asked children to complete simple actions (e.g., "Put your hands on your head") much like in *Simon Says* (Carlson, Moses, & Breton, 2002; Reed, Pien, & Rothbart, 1984). Children were instructed to listen to only one of the puppets ("the nice bear") and to ignore the instructions of the other puppet ("the mean dragon"). There were 6 inhibition (i) trials and 6 activation (a) trials presented in the same predetermined order for all children (a, a, i, a, i, i, i, a, i, a, i, and a). Scores were summed across the 6 inhibition trials (and reversed). Only this total was used in the inhibitory control composite. Responses were scored as 3 (*fully completed the command*), 2 (*completed* *a wrong command*), 1 (*partially completed the command*), or 0 (*did not complete the command*). Interrater reliability was assessed using kappa, which was .96.

Day/night

Children viewed picture cards and were instructed to say the opposite of what the picture represented in this Stroop-like task (Carlson, 2005; Gerstadt, Hong, & Diamond, 1994). Specifically, children were instructed to respond to the sun picture by saying "night" and to the moon and star pictures by saying "day." Two practice trials were completed with feedback. During the test phase, the researcher administered eight "day" (d) and eight "night" (n) cards in a pseudorandom sequence (n, d, d, n, d, n, n, d, d, n, d, n, n, d, n, and d) with no corrective feedback. Responses and latency were recorded. Interrater reliability was assessed using intraclass correlations, revealing coefficients of 1.0 for response total and .98 for latency.

Whisper

Children were asked to whisper the names of cartoon characters depicted on small cards (Carlson et al., 2002; Kochanska et al., 1996). First, children were asked to complete a practice trial of whispering their name. During the test phase, cards were presented in the following randomized order: Fred Flintstone, Dora, Mickey Mouse, Sponge Bob, Cinderella, Spiderman, Winnie the Pooh, Shrek, Arthur, Scooby Doo, Bugs Bunny, and Blue (of Blue's Clues). Fred Flintstone and Bugs Bunny were unfamiliar to many children. Responses were coded as 0 (*shout*), 1 (*part loud, part whisper*), 2 (*no response or "I don't know*"), or 3 (*whisper*). Scores were summed across the 12 trials. Interrater reliability was assessed using kappa, which was .96.

Gift delay

This task was designed to determine the extent to which children were able to suppress the desire to look at a gift being noisily wrapped until allowed to view it (Carlson et al., 2002; Kochanska et al., 1996). Children were told that the researcher would wrap a gift while kneeling behind their back and that they should not peek until the researcher said it was okay to do so. The researcher proceeded to noisily wrap a jar of Play-Doh for 1 min. When this time had elapsed, children unwrapped the gift to keep. Children were then allowed to choose a second small gift. Latency until first peek was coded. In addition, the total number of peeks during the 1 min was coded. Finally, peek resistance was coded as 2 (*no peeking*), 1 (*peeking over shoulder*), or 0 (*a full torso turn*). Interrater reliability was assessed using intraclass correlations, revealing coefficients of 1.0 for latency and .99 for total number of peeks. Kappa for peek resistance was 1.0.

Parent questionnaires

CBQ short form

The short form of the CBQ parent-report measure contains 94 items used to assess behavior and temperament in children between 3 and 7 years of age (Putnam & Rothbart, 2006). In particular, parents rate each statement on a scale from 1 (*extremely untrue of my child*) to 7 (*extremely true of my child*), with the option of marking *not applicable* for any question. The scales of interest for this study included the Attentional Focusing subscale (tendency to maintain attentional focus on task-related channels) and the Inhibitory Control subscale (capacity to plan and suppress inappropriate approach responses under instructions or in novel or uncertain situations) of the CBQ. Six statements contributed to each of these subscales. They were scored according to standard procedures. The Attentional Focusing subscale contributed to the parent-rated attention composite (predictor variable), and the Inhibitory Control subscale served as a dependent variable. In the current study, the Inhibitory Control subscale had a coefficient alpha of .63, and the Attentional Focusing subscale had a coefficient alpha of .71.

BASC-2: Parent rating scale

One parent for each child completed the appropriate BASC-2: parent rating scale (BASC-2 PRS; Reynolds & Kamphaus, 2004) form: the BASC-2 PRS-P (Preschool) for children who were between 3 and 5 years of age and the BASC-2 PRS-C (Child) for children who were 6 years of age. Parents rated how often particular child behaviors occur (*never, sometimes, often,* or *always*), focusing on a variety of problem behaviors, school difficulties, and adaptive skills. The BASC-2 PRS-P contains 134 items, and the BASC-2 PRS-C contains 160 items. T scores were used in this investigation. The Attention Problems subscale (6 items) and the Executive Functioning subscale (13 items on the PRS-P and 10 items on the PRS-C) contributed to the parent-rated attention composite (predictor variable). The original version of the BASC and the updated version have been used extensively in research and evince strong reliability and validity (Reynolds & Kamphaus, 2004). Each scale has internal consistency (as measured by coefficient alphas) between .73 and .89.

Individual variables were checked for normality (skewness and kurtosis) and were log-transformed when these indicators suggested distributions that were non-normal. Composite variables were created for data reduction purposes. Given that the parent rating scale assessed general aspects of inhibitory control across a variety of contexts (Liebermann et al., 2007) and that complex executive functioning tasks often are "impure" in tapping multiple aspects of the construct (Lehto et al., 2003), we chose to aggregate across our inhibitory control tasks and measures to create an observational inhibitory control score similarly broad in scope. Moreover, following the principle of aggregation had the potential to increase the robustness of our findings (Rushton, Brainerd, & Pressley, 1983). We relied on theoretical and empirical considerations when forming aggregate measures.

The observational inhibitory control composite measure consisted of the total Whisper score, the number of correct trials in Day/Night, the total latency during Day/Night (reversed), the inhibition trials in Bear/Dragon (reversed), the latency to peek in Gift Delay, the total number of peeks during Gift Delay (reversed), and the peek resistance score in Gift Delay. These seven scores were subjected to z score transformations and combined to form an inhibitory control composite that evinced good internal consistency (alpha = .80). Higher scores indicated greater inhibitory control.

A parent-rated attention problems composite score was created from the Attention Problems subscale (T score) from the BASC-2, the Executive Functioning subscale (T score) from the BASC-2, and the Attention Focusing subscale from the CBQ (reversed). These three scores were subjected to z score transformations and combined to form a parent-rated attention problems composite that evinced good internal consistency (alpha = .83). Higher scores indicated greater attention problems.

The parent-rated inhibitory control score came directly from the Inhibitory Control subscale of the CBQ. Higher scores indicated greater inhibitory control. Finally, measures of omission and commission were analyzed as separate predictors, as were parent reports of attention problems. Methodologically, this decision was motivated by the emergent nature of this work using sustained attention measures during the preschool years. Moreover, previous theoretical and empirical work has shown different patterns of relations for omissions and commissions. Specifically, errors of omission tend to be related to inattention, whereas errors of commission tend to be related to hyperactivity (Halperin, Wolf, Greenblatt, & Young, 1991). Thus, using a variety of sustained attention measures allowed us to determine whether there was consistency among the ways in which various measures of sustained attention (and parent-rated attention problems) predicted inhibitory control.

Results and discussion

The goal of this investigation was to determine whether sustained attention and age predict inhibitory control. Table 1 shows correlations for all dependent measures. Omissions, commissions, and parent-rated attention problems were entered into separate cross-product regression analyses (along with age) to determine whether there was consistency in predicting observational and parent-rated inhibitory control. We used centered cross-product regression to avoid artificially dichotomizing continuous variables (Aiken & West, 1991). Regression results are summarized in Table 2. There was a significant interaction of omission and age in predicting observational inhibitory control, showing that fewer omission errors were associated with more inhibitory control in younger children but not in older children. In addition, when using commission and age to predict observational inhibitory control, the main effects of age and commission were significant. There was no evidence of an interaction. When using the parental questionnaire attention problems composite and age to predict observational

Table 1
Correlations for individual variables and composite scores.

Measure	Whisper total	Day/night total	Day/night latency	Bear/dragon inhibition	Gift delay peek latency	Gift delay total	Gift delay peek resistance	Observational inhibitory control composite	CBQ Inhibitory Control	PDTP-R omissions	PDTP-R commissions	BASC-2 Attention Problems	BASC-2 Executive Functioning	CBQ Attentional Focusing	Parent-rated attention problems composite
Whisper total	–														
Day/night total	.31**	–													
Day/night latency	–.17	–.31**	–												
Bear/dragon inhibition	–.42**	–.29**	.36**	–											
Gift delay peek latency	.21*	.32**	–.21*	–.26**	–										
Gift Delay total	–.18	–.32**	.29**	.27**	–.84**	–									
Gift delay peek resistance	.19	.27**	–.18	–.26**	.89**	–.81**	–								
Observational inhibitory control composite	.53**	.60**	–.53**	–.62**	.80**	–.79**	.77**	–							
CBQ inhibitory control	.24*	.42**	–.31**	–.22*	.21*	–.20*	.22*	.39**	–						
PDTP-R omissions	–.32**	–.49**	.40**	.49**	–.38**	.45**	–.34**	–.62	–.41**	–					
PDTP-R commissions	–.03	–.13	.15	.34**	–.04	.04	–.01	–.16	–.15	.26**	–				
BASC-2 attention problems	–.18	–.33**	.15	.06	–.15	.17	–.25*	–.27**	–.68**	.26**	.07	–			
BASC-2 executive functioning	–.07	–.30**	.06	.04	–.15	.18	–.24*	–.22*	–.56**	.36**	.05	.73**	–		
CBQ attentional focusing	.11	.28**	–.18	–.25*	.19	–.19	.26**	.31**	.64**	–.31**	–.21*	–62**	–.50**	–	
Parent-rated attention problems composite	–.13	–.35**	.15	.13	–.19	.21*	–.29**	–.31**	–.73**	.36**	.13	.91**	.86**	–82**	–

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

Table 2
Cross-product regression analyses of omission, commission, or parent-reported attention problems composite and age predicting observational and parent-reported inhibitory control.

Model and predictors	*df*	*t*
Predicting observational inhibitory control		
Omission × age	90	4.87***
Younger children	90	−6.56***
Older children	90	−0.10
Commission	91	−2.05*
Age	91	5.43***
Commission × age	90	1.37
Parent-reported attention problems	98	−2.54**
Age	98	7.14***
Parent-reported attention problems × age	97	1.39
Predicting parent-reported inhibitory control		
Omission	90	−3.07**
Age	90	0.22
Omission × age	89	1.10
Commission	90	−2.27*
Age	90	1.74†
Commission × age	89	1.26
Parent-reported attention problems	98	−10.12***
Age	98	2.48*
Parent-reported attention problems × age	97	−0.82

† $p < .086$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

inhibitory control, the main effects of age and parent-rated attention problems were significant. Again, there was no evidence of an interaction.

It was hypothesized that sustained attention and age also would predict parent-rated inhibitory control. When using omission and age to predict parent-rated inhibitory control, the main effect of omission was significant. There was no evidence of a main effect of age or of an interaction. When using commission and age to predict parent-rated inhibitory control, the main effect of commission was significant and the main effect of age was marginally significant. There was no evidence of an interaction. Finally, when using parent-rated attention problems and age to predict parent-rated inhibitory control, the main effects of age and parent-rated attention problems were significant. There was no evidence of an interaction.

Exploratory factor analysis with promax rotation was used to provide additional empirical evidence regarding the factor structure evident here, focusing particularly on observational attention (i.e., omission and commission errors) and inhibitory control measures (i.e., composite scores for each inhibitory control task created so that positive scores reflect greater inhibitory control). As expected, inspection of the scree plot revealed that two factors had eigenvalues greater than 1.0, so a two-factor model provided the best solution (see Table 3). Although testing the difference between one- and two-factor models was not feasible given that Factor 2 contained only one variable, confirmatory factor analysis revealed that the two-factor model fit was reasonable, $\chi^2(8) = 13.97$, $p = .08$, root mean square error of approximation (*RMSEA*) = .086. Together, these findings confirm that sustained attention (especially commission errors) is distinct from inhibitory control.

One limitation of this study was that it did not include a measure of verbal ability or intelligence quotient as a control factor. Nonetheless, the study extends the extant literature in several important ways. First, sustained attention predicted observational inhibitory control and parent-rated inhibitory control such that increasing attention problems predicted less inhibitory control. These findings shed

Table 3
Factor loadings for exploratory factor analysis with promax rotation of inhibitory control and attention observational measures.

	Factor 1	Factor 2
Omission errors	−**.73**	.07
Day/Night	**.67**	.01
Gift Delay	**.61**	.17
Bear/Dragon	**.56**	−.26
Whisper	**.52**	.10
Commission errors	.12	**.81**

Note. Factor loadings greater than .40 are in boldface.

light on potential mechanisms underlying the development of executive functioning components and also add to the growing preschool attention literature (DeWolfe et al., 1999; Sonuga-Barke, Dalen, Daley, & Remington, 2002). Similarly, attention (particularly commission errors) and inhibitory control were separate components. Second, age was a powerful predictor of inhibitory control, confirming previous findings showing dramatic improvements in executive functioning during early childhood (Carlson, 2005). Third, our results support the utility of multimethod assessment of attention and executive functioning. As such, the current findings add to our growing understanding of the mechanisms underlying the development of executive functioning during early childhood.

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