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Sequence imitation and reaching measures of executive control: A longitudinal examination in the second year of life

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Abstract

Despite increasing interest in the early development of executive control, few assessment tools are available for use in the second year of life. At 15 and 20 months, children completed a task battery that included reaching and sequence imitation tasks expected to require executive control. With age, children showed reduced perseveration and increased ability to resist interference across trials and from distractors. At each age, A-not-B with invisible displacement was correlated with one of the sequence imitation tasks modified to increase executive control demands. Correlations between child performance on individual tasks at 15 and 20 months were generally low.

The term *executive control* encompasses the cognitive processes that underlie the capacity for goal-directed behavior (e.g., working memory, motor and cognitive inhibition, resisting interference from distractors, and set-shifting; Miyake et al., 2000; Stuss & Alexander, 2000). Executive control depends on neural circuits involving prefrontal cortex (Duncan & Owen, 2000), which have a protracted course of development relative to other cortical regions (Benes, 2001; Huttenlocher, 1990); correspondingly, the development of executive control is delayed relative to other cognitive functions (Welsh, Pennington, & Groisser, 1991). Across the transition from infancy to early childhood, behavior increasingly becomes the product of endogenous, goal-directed processing rather than obligatory reactions to stimuli. However, the development of executive control in the transition from infancy to early childhood is relatively poorly understood, and few assessment tools are available for their study (Hughes & Ensor, 2005; Wiebe & Bauer, 2005).

Although relatively few studies have examined executive control in the second year of life, there are indications that this period is marked by substantial improvements in executive control and related abilities. Search tasks have revealed decreases in perseverative reaching tendencies (Diamond, Lee, & Hayden, 2003; Rieser & Heiman, 1982; Zelazo, Reznick, & Spinazzola, 1998). Ruff and Rothbart (1996) identify a sharp increase in the involvement of executive attention systems at approximately 18 months. Improvements in cognition are most likely connected with developments in the ability to regulate behavior under varying contexts and demands. Across the second year, toddlers begin to use more complex strategies to regulate their emotions (Kopp, 1989; Lewis, Zimmerman, Hollenstein, &

Lamey, 2004) and are increasingly able to exert self-control (Vaughn, Kopp, & Krakow, 1984). Furthermore, this period has relevance to the emergence of clinical symptomatology in disruptive behavior disorders, which are thought to relate to executive control deficits (Nigg & Casey, 2005; Olson, Bates, Sandy, & Schilling, 2002). For example, in a study of the effects of prenatal tobacco exposure on children's externalizing behavior problems, Wakschlag, Pickett, Cook, Benowitz, and Leventhal (2006) found that differences between tobacco-exposed and non-exposed children were first evident at the end of the second year of life. For all these reasons, better insight into executive control in the second year will have broad implications for the understanding of early development and possible intervention.

Assessment of behavior and cognition in the second year requires overcoming several challenges. Because toddlers vary greatly in their linguistic competence, verbal tasks are inappropriate for this age group. Tasks need to be game-like so that children will perceive them as enjoyable, with minimal requirements that children understand complicated verbal instructions or arbitrary rules. Consequently, it is not possible to use the same tasks across the age range when we know the frontal systems are developing, that is, infancy, childhood, and adolescence. This issue is one of both practicality and construct validity. A task appropriate for older children would be impossible for infants and young children to perform, whereas a task that could be used with infants would be trivially easy for older children, and would make minimal or no executive demands. Previous studies of executive control in the second year have featured tasks requiring a variety of behaviors, including finding hidden objects (Diamond, Prevor, Callender, & Druin, 1997; Zelazo, Reznick, & Spinnazola, 1998), stair-climbing (Berger, 2004), spatial navigation (Rieser & Hieman, 1982), and action sequence imitation (Bauer, Schwade, Wewerka, & Delaney, 1999; Wiebe & Bauer, 2005).

Imitation of action sequences is a tool that has proven useful for the assessment of cognitive competence in infants and young children. Children have a natural tendency to imitate—in fact, several of Luria's original "frontal" tasks take advantage of the prepotency of imitation (Luria, 1966). Typically-developing children with immature frontal lobes and adults with prefrontal lesions have difficulty following a rule requiring them to suppress an imitative response, such as tapping a block twice when the examiner taps once (e.g., Diamond & Taylor, 1996). In the elicited imitation task, originally developed to study early memory development, an examiner demonstrates action sequences using novel props, and children are permitted to imitate the examiner's actions immediately or after a delay (Bauer, 2004). Deferred imitation studies have enabled quantification of what very young children can remember, and for how long (Bauer, Wenner, Dropik, & Wewerka, 2000; Carver & Bauer, 2001). Although the prefrontal cortex is important for sequence representation (Shimamura, 1995), adults with prefrontal lesions perform normally on deferred imitation of sequences similar to those used in elicited imitation studies with children, whereas adults with temporal lobe damage are impaired (McDonough, Mandler, McKee, & Squire, 1995). However, these sequences typically include enabling relations, so that each step of the sequence facilitates the next (Bauer, 1992; Bauer & Fivush, 1992). As such, their order is temporally constrained. For these reasons, standard elicited imitation methods most likely do not reflect executive control. However, sequence imitation tasks can be modified to increase executive demands, and have already proven useful in measuring executive control in toddlers.

In one such study, Wiebe and Bauer (2005) incorporated several modifications to the standard elicited imitation paradigm that were designed to generate interference, a context known to invoke executive control processes (Friedman & Miyake, 2004). Children who were 20 and 27 months of age were shown several action sequences before they were given the opportunity to imitate, so that proactive or retroactive interference could potentially

come into play. The array of props presented at the imitation test phase included distractors, so that children had to select the items needed to successfully imitate the sequence. The presence of the distractors at test impaired children's performance, and even when the distractors were removed from the array, children's level of performance remained below performance on control sequences. However, there was no evidence for proactive or retroactive interference between sequences at encoding. Bullock and Lütkenhaus (1988) used a conceptually similar block-building task, in which 1- and 2-year-old children were asked to build towers out of blocks painted to depict parts of a whole (e.g., the roof, window, and door of a house), and children were also provided with additional, unpainted blocks. There were qualitative differences in performance across age, in that younger children were less likely to achieve the goal, and more likely to become distracted by the unpainted blocks and include them in their towers.

In another study, 20- and 27-month-old children were given only some of the information required for successful sequence imitation (Bauer et al., 1999). Children were shown only part of the sequence necessary to achieve a goal (e.g., make a toy dance). To perform optimally, children had to generate the missing information, hold the required actions in working memory, and construct the correct sequence of actions to achieve the goal. Even the 20-month-old group benefited from seeing the sequence goal, and performed above baseline levels when the demonstration included the end-state, but performed poorly when shown parts of the sequence that did not include the goal.

Although modified sequence imitation tasks appear to hold promise in the study of executive control early in life, a number of questions remain unanswered. So far, these tasks have demonstrated sensitivity to developmental change as young as 20 months—but what about younger children? Furthermore, it has not yet been shown that these tasks are indeed measuring the same constructs as other toddler measures of executive control. To address these questions, in the present study, a group of children were tested with several sequence imitation tasks early and late in the second year, at 15 and 20 months of age. We also included several measures of executive control that were appropriate for use in the second year that did not include an imitative component, selected on the basis of a review of the literature.

Perhaps the most studied measure of executive control in infancy is the A-not-B task, which is argued to require working memory for a hidden object's location and inhibitory control of the prepotent response to reach back to a previously successful location (Diamond, 1990). Prefrontal involvement in this task is supported by studies of nonhuman primates (Diamond & Goldman-Rakic, 1989) and neuroimaging work with human infants (Bell, 2001; Bell & Fox, 1997). The standard A-not-B task is no longer a sensitive measure in the second year; however, addition of invisible displacement to the A-not-B procedure increases the task difficulty so that it is appropriate for 1- and 2-year-olds (Diamond et al., 1997). Diamond et al. found that this task differentiated between 2-year-old children with phenylketonuria (PKU; associated with selective damage to dopaminergic circuits implicated in executive control) and typically-developing children of the same age.

Diamond et al. (1997) also included the Three Boxes task, based on the self-ordered pointing working memory task developed for nonhuman primates, in which multiple items or locations must be selected without repetition (Petrides, 1995). Results were mixed: children's task performance did not significantly improve with age between 15 and 30 months, nor did performance differentiate children with PKU from controls. However, Diamond et al. discuss several possible explanations for these findings. They also included a condition in which the boxes were not scrambled as a lower-demand comparison, and unexpectedly, children performed more poorly on the unscrambled version of the task than

on the scrambled version, and became less likely to reach perseveratively to the same location as they got older. If the boxes are scrambled randomly on each trial, children who reach to the same location will eventually find all three toys despite using a perseverative strategy rather than remembering which boxes they have opened previously. Developmental improvements in using the correct strategy (i.e., remembering which boxes had been opened) would not necessarily result in improvements in performance. We included this measure in our battery as well, but made some procedural modifications to reduce the efficacy of a perseverative reaching strategy (see Method).

The present study was a longitudinal investigation of executive control in the second year of life. Children completed the same battery of executive control tasks when they were 15 and 20 months old. Our goal was to administer a battery of tasks including both sequence imitation and reaching-based measures, and examine the pattern of change over time and the relations between tasks within and across time-points.

Method

Participants

The sample included 30 one-year-old children (16 girls, 14 boys). The children had participated in a study of infant memory and executive control when they were 9 months old (Wiebe, Lukowski, & Bauer, 2002). Most of the children were Caucasian, reflecting the demographics of the Midwestern city where the study took place. Participants were originally recruited from a database of families who indicated their willingness to participate in research. All children were born within two weeks of their due date, and parents indicated that their development was proceeding normally. Testing was conducted by two female examiners. Each examiner tested half of the children, and each child saw the same examiner at each session. Participants visited the lab for a total of four visits: twice at 15 months (mean age 15 months; range 14;24 – 15;11), and twice at 20.5 months (mean age 20 months 14 days; range 20;08 – 20;23). When possible, visits at each age were scheduled on two consecutive days, and were scheduled at times not conflicting with regular naps or mealtimes. In practice, due to factors such as parental availability and child illness, the delay between visits ranged between 1 and 4 days ($M = 1.4$ days at 15 months, 1.3 days at 20 months).

Procedure

At each age, participants were administered the same battery of tasks in a fixed order determined on the basis of pilot testing (different from the order in which tasks are described here), in order to minimize differential effects of fatigue and order of presentation. The rationale and procedures for each task are provided below. Sessions were videotaped, and each task was transcribed from videotape by trained coders who were naive to the specific hypotheses of this study. For each task, data for 8 children (27% of the sample) were independently transcribed by a second coder. For the reaching tasks (A-not-B and Three Boxes), average agreement was 99% (range = 97 – 100%). For the imitation tasks, average agreement on the occurrence and order of sequence actions was 90% (range = 84 – 93%). At 15 months, two children had missing data for the planning task and one child had missing data for Three Boxes because of recording equipment failure at one of their sessions.

A-not-B with invisible displacement (Diamond et al., 1997)—Task materials included two identical yellow barrel-shaped plastic containers with yellow covers; a blue plastic barrier with a stopwatch affixed to one side; and an assortment of toys that fit inside the containers. Before testing began, the child was familiarized with one of the containers and the array of toys, and the examiner selected several toys that held the child's interest.

Next, the examiner hid a toy in one of the containers, and the child was encouraged to open the container and retrieve the toy. Two pre-trials were administered to introduce invisible displacement: the toy was hidden in the container at the child's midline, and then the container was moved to one side, in the child's view. Then the barrier was placed between the container and the child. After a 5-second delay, the barrier was removed and the child was encouraged to reach for the container, and retrieve the hidden toy. To ensure that children reached successfully to both sides before test trials began, each child was administered a pre-trial at each side; order was counterbalanced across participants. The procedure for test trials was the same as the pretrial, except that during the delay, an identical (but empty) container was placed in the opposite position behind the barrier, and the examiner distracted the child to prevent fixation on the correct location. After the delay, the barrier was removed and the child was allowed to retrieve one of the containers. Whenever the child reached a criterion of two consecutive correct trials at one location, the location was switched on the next (reversal) trial. Testing was continued until four reversals had been administered or the child refused to continue. Performance on the first and second post-reversal trials was scored separately, along with the number of reversal sets administered and the number of trials administered before the criterion of two consecutive correct trials was attained. Children who never reached criterion were assigned a score of 0 on the post-reversal measures to permit their inclusion in the analyses. At 15 months, 5 children did not reach criterion, and at 20 months, 3 different children did not reach criterion.

Three Boxes task (Diamond et al., 1997)—Materials for this task included Three Boxes that differed in shape and color, with covers attached to the boxes by a string and ornamented with distinctive shapes; assorted toys that fit inside the boxes; and the same blue plastic barrier used in A-not-B testing. At each age children completed two blocks of trials. A toy was hidden in each box, in the child's view. On each trial, the child was permitted to open one box, then the examiner put the barrier in place and scrambled the boxes during a 5-second delay. Initially, boxes were scrambled pseudo-randomly, but when only one toy remained to be found, box location was constrained so that the filled box was never placed where the child had reached on the previous trial. This meant that children could not succeed by reaching perseveratively to the same location. A block ended when all toys had been found or after five consecutive errors. The key dependent measure was the number of reaches required to find all toys; perfect performance (3 reaches) is indicative of memory for the particular boxes that have already been opened. To allow examination of developmental change in task strategies, the longest run of consecutive reaches to the same location and box were tallied. All dependent measures were averaged across blocks.

Immediate imitation—Elicited imitation has been developed to assess memory in preverbal infants and young children. Stimuli are props that can be used to achieve novel, interesting outcomes or goals through a fixed number of actions, which must be performed in a constrained sequence to achieve the goal. Each sequence used a unique set of props. A total of 24 sequences were used in the three imitation-based tasks included in this study. A full list is provided in the Appendix, and a sample sequence is described for each task variant. No child saw the same sequence more than once, and for all sequence imitation tasks the dependent measures were the number of sequence actions (indexing memory for individual items) and correctly-ordered pairs (indexing memory for order information) produced during each test phase.

Because the test battery included two modified elicited imitation tasks designed to increase executive demands, the standard immediate imitation task was included as a comparison. The test procedure for each sequence involved three phases. First, in a baseline assessment, the child was allowed to explore the props used in the sequence for a child-controlled

duration, until the child was no longer interested in the props (typically indicated by pushing them toward the examiner or engaging in repetitive play; cf. Bauer et al., 2000). Next, the examiner took back the props and modeled the action sequence twice, with a verbal label of the sequence and narrative description of the steps. For example, for the sequence “gong” the examiner said, “I can use this stuff to make a gong: put on the bar, hang up the bell, ring it!” Finally, following modeling, the props were returned to the child for another child-controlled interval, with the verbal prompt “Now show me what you can do with this stuff.” As in previous research using the standard elicited imitation task, different sequence lengths were used at each age (Bauer et al., 2000). At 15 months, each child was tested on two 3-step sequences drawn from a pool of four. At 20 months, each child was tested on two 4-step sequences drawn from a pool of five. Because the sequence lengths differed across age, there were age differences in the number of possible actions and pairs, so dependent measures were converted to proportions.

Imitation with Distractors (Wiebe & Bauer, 2005)—Two trials were administered at each age; each trial required the materials for two 3-step sequences. For each child, the 8 sequences required for this task were drawn from a pool of 10, and counterbalanced across age. The examiner first modeled one sequence (e.g., “I use this stuff to make a paddle rattle: put on the spinner, put on the cover, shake it!”). The examiner then modeled a second sequence (e.g., “I use this stuff to make the squid jump: put on the seesaw, put on the squid, make it jump!”). After both sequences had been demonstrated, the child received an array of props that included all of the props for the first sequence (paddle rattle), and those props necessary to complete the first step of the second sequence modeled (in this example, the seesaw and base, but not the squid, which was required for sequence completion). Thus only the first sequence could be produced in its entirety, and children had to select and utilize a subset of the props to successfully imitate a sequence and attain one of the modeled goals. When the array of props was first presented, the examiner provided only general verbal cues (e.g., “What can you do with this stuff?”). When the child no longer was making further progress toward the goal, the examiner provided the verbal label for the first sequence modeled (e.g., “You can use some of this stuff to make a paddle rattle”). The child was then given more time to attempt problem solution. Finally, the examiner removed the props used in the second sequence, so that the child had only the complete set of props for the first sequence. In prior research (Wiebe & Bauer, 2005), both verbal labeling and removal of distractor props benefit 20-month-olds’ performance on this task, but their efficacy for younger children is unknown. The child’s production of sequence actions and pairs was scored separately for each test phase (initial presentation, after verbal prompt, and after removal of distractor props), following the procedures used by Wiebe and Bauer (2005): children received credit for sequence actions and pairs only at their first occurrence, and analyses of performance at each cue phase were conducted including previous performance as a covariate, to statistically control for the number of actions that remained to be imitated.

Planning (Bauer et al., 1999)—Two trials were administered at each age, requiring two 3-step sequences; the same 4 sequences were used across the 2 ages, and were counterbalanced so that each sequence was tested equally often at each age. A trial began with a baseline test phase. The child was given the props necessary to complete the sequence, and allowed to explore them for a child-controlled length of time. The examiner retrieved the props, partially assembled them under the table out of the child’s view, and then demonstrated the third step (i.e., the goal state) twice, labeling the sequence and providing narration for the third step (e.g., “I use this stuff to make a drum: play the drum!”). The examiner then disassembled the props out of the child’s view and gave them to the child. The child then was allowed to attempt problem solution for a child-controlled interval. Finally, the examiner retrieved the props again, and demonstrated the full sequence

twice, labeling the sequence and providing narration for the entire sequence (e.g., “Watch everything I do to make a drum: put in the paddle, put on the lid, play the drum!”). The child then was given the props one more time and was given the opportunity to imitate the examiner’s actions. The child’s production of sequence actions and pairs was scored separately for each test phase (baseline, end-state demonstration, and full-sequence demonstration).

Results

Developmental Change in Task Performance

Analyses were conducted in SAS 9.1. Descriptive statistics for each task and ranges of possible scores are presented in Table 1. Sample statistics were used to compute the observed power of age effects using *Proc Power*, and these values are also included in Table 1. Developmental differences in performance for each task were analyzed using *Proc GLM*, using analysis of variance (ANOVA) or analysis of covariance (ANCOVA) as appropriate. Following Bakeman’s (2005) recommendations for studies utilizing repeated measures, effect sizes are given as generalized eta-squared statistics (η^2_G). Considered within Cohen’s (1988) framework, an η^2 of .02 represents a small effect, .13 is considered a medium effect, and .26 is a large effect.

A-not-B with invisible displacement—Each dependent measure was analyzed using an ANOVA with repeated measures on age (15, 20 months). Children completed significantly more reversals at 20 months than they did at 15 months, $F(1, 29) = 6.17, p < .02, \eta^2_G = .10$. Other variables did not differ significantly across age. The proportion of correct responses on the first post-reversal trial did not change from 15 to 20 months, $F(1, 29) = 0.28, p = .60$; change in performance on the second post-reversal trial also was not statistically significant, $F(1, 29) = 3.94, p = .06$. Children required an equivalent number of trials to reach criterion at both ages, $F(1, 24) = 0.84, p = .37$.

To better characterize children’s performance, the proportion of correct trials on first and second post-reversal trials was compared against chance. At 15 months, children performed significantly below chance (50%) on both first and second post-reversal trial, $ts(29) = -3.72$ and $-4.55, ps < .001$. At 20 months, children’s responses were below chance level on the first post-reversal trial, $t(29) = -3.05, p < .005$, but were roughly at chance on the second trial, $t(29) = -1.49, p = .15$. The age-related decrease in the number of reversals completed likely is an indirect measure of decreases in perseveration, as testing was discontinued earlier for children who persisted in making the A-not-B error over a long series of trials, and thus failed to reach criterion for the next reversal to be administered. The observation that there was no significant change in the number of trials required for children to reach criterion initially suggests that any change over time reflected the ability to overcome perseverative responding rather than difficulty with initial learning.

Three Boxes—Each dependent measure was analyzed in an ANOVA model with repeated measures on age. All performance indices improved significantly from 15 to 20 months. As children got older, they required significantly fewer reaches to find all hidden toys, $F(1, 28) = 7.74, p < .02, \eta^2_G = 0.13$. The longest run of consecutive reaches to the same spatial location was shorter at 20 than 15 months, $F(1, 28) = 6.98, p < .02, \eta^2_G = 0.09$; similarly, the longest run of reaches to the same box was shorter at the later time-point, $F(1, 28) = 5.41, p < .05, \eta^2_G = 0.08$.

To examine relations between children’s efficiency in finding all hidden toys and indices of perseveration, we conducted regression analyses using SAS’s *proc reg*, which are summarized in Table 2. The degree to which children evidenced perseverative reaching,

either by reaching to the same box or the same location on multiple consecutive trials, accounted for most of the variance in the number of trials required to complete the task at both ages (81% at 15 months, 74% at 20 months). At 15 months, standardized slope coefficients were equivalent for both types of perseverative reaching, but at 20 months the coefficient was substantially larger for reaching back to the same box than for reaching back to the same location. Importantly, our modification of the task administration procedure (relative to Diamond et al., 1997) was successful in preventing children from achieving spuriously high levels of performance on the task using a perseverative strategy.

Immediate imitation—Children's production of sequence actions and correctly-ordered pairs were analyzed separately using 2 (age) $\times$ 2 (phase: baseline, imitation) ANOVA models with repeated measures on both age and phase. Overall, children produced a higher proportion of sequence actions at 20 months than they did at 15 months, $F(1, 29) = 6.17$, $p < .02$, $\eta^2_G = 0.05$ ($M_s = 47\%$ and 57% of sequence actions, $SD_s = 0.31$ and 0.30 , at 15 and 20 months, respectively). There was also an effect of phase: children's performance improved significantly from baseline to imitation, $F(1, 29) = 180.61$, $p < .0001$, $\eta^2_G = 0.53$ ($M_s = 30\%$ and 74% , $SD_s = 0.20$ and 0.23 , at baseline and imitation, respectively). The interaction between age and phase was not significant, $F(1, 29) = 1.30$, $p = 0.26$. The proportion of correctly-ordered pairs did not differ significantly across age, $F(1, 29) = 1.24$, $p = .28$. There was a significant effect of phase: $F(1, 29) = 139.78$, $p < .0001$, $\eta^2_G = 0.48$, $M_s = 11\%$ and 50% of possible correctly-ordered pairs at baseline and imitation respectively. This was qualified by a significant age by phase interaction, $F(1, 29) = 4.37$, $p < .05$, $\eta^2_G = 0.02$. The interaction was followed up by examining the effect of phase separately at 15 and 20 months. There was a significant effect at both ages but the effect size was nearly double at the older time-point, $F_s(1, 29) = 53.95$ and 158.10 , $p_s < .0001$, $\eta^2_G = 0.35$ and 0.64 at 15 and 20 months respectively (means are given in Table 1). Thus, there were clearly developmental improvements in the imitation of action sequences between 15 and 20 months, consistent with previous reports (Bauer et al., 2000). Most importantly for the present study, children were clearly capable of imitating actions in sequence at both time-points, so poor performance in the modified versions can be attributed to the executive control manipulation.

Imitation with distractors—Sequence actions and pairs were analyzed separately for each test phase: initial performance, after the verbal cue was given, and after distractor props were removed. In the initial phase, performance was analyzed using an ANOVA with repeated measures on age. As in Wiebe and Bauer (2005), children could only receive credit for producing each sequence action once, as the props were not reset between phases, so performance at later phases was analyzed using an ANCOVA with repeated measures on age, and including earlier performance as a covariate. In the initial uncued phase, children produced significantly more sequence actions at 20 months than 15 months, $F(1, 27) = 38.68$, $p < .0001$, $\eta^2_G = 0.31$, as well as more pairs, $F(1, 27) = 31.34$, $p < .0001$, $\eta^2_G = 0.30$. Children benefited more from the verbal cue at 20 months than they did at 15 months, producing more new components, $F(1, 26) = 9.82$, $p < .005$, $\eta^2_G = 0.12$, and more correctly-ordered pairs, $F(1, 26) = 4.59$, $p < .05$, $\eta^2_G = 0.05$. There was no age difference in performance after distractor props were removed for components, $F(1, 26) = 3.09$, $p = .09$, or for pairs, $F(1, 26) = 0.09$, $p = .77$. This may be attributable to older children's better performance at earlier phases. Across all three test phases, children at 15 months produced an average of 1.45 sequence actions, or approximately half of the sequence, whereas at 20 months children produced an average of 2.63 sequence actions, indicating that most children at 20 months were successful at completing the whole sequence, although the observation that total production of ordered pairs across all phases was 1.17 (out of 2 possible pairs) shows that sequence production was not errorless. At 20 months, children were able to

overcome the interference from distractor props, but at 15 months this interference persisted across test phases.

Planning task—The Planning task assesses children's ability to use information about a sequence's end-state or goal to generate the entire sequence. To evaluate children's planning behavior at each age, sequence actions and correctly-ordered pairs were analyzed using 2 (age) $\times$ 3 (phase: baseline, end-state, full demonstration) ANOVAs, with repeated measures on both age and phase. For both dependent measures, there were significant main effects of age, $F_s(1, 29) = 9.97$ and 12.52 , $p_s < 0.005$, $\eta^2_G = 0.06$ and 0.06 for actions and pairs respectively, and phase, $F_s(2, 58) = 45.14$ and 40.23 , $p_s < 0.0001$, $\eta^2_G = 0.30$ and 0.37 . For both sequence actions and correctly-ordered pairs, main effects were qualified by interactions between age and phase, $F_s(2, 58) = 3.73$ and 4.18 , $p_s < .05$, $\eta^2_G = 0.02$ and 0.02 . To follow up these interactions, the effect of phase was examined at each age. For both sequence actions and correctly-ordered pairs, the effect of phase was significant at both ages, $F_s(2, 29) = 17.42$ and 17.27 at 15 months ($\eta^2_G = 0.22$ and 0.39), 41.77 and 48.19 at 20 months ($\eta^2_G = 0.30$ and 0.43), $p_s < .0001$. For both sequence actions and pairs, Tukey tests showed that at 15 months, children performed equivalently at baseline and after seeing the end-state demonstration; performance improved only after they saw the complete sequence demonstration. However, at 20 months, performance on all 3 phases differed. Thus, at 15 months there was no indication that children used end-state information to generate and order the necessary preliminary steps. In contrast, at 20 months, children were able to generate part of the problem-solution through demonstration of the end-state, but performance improved further upon demonstration of the full sequence.

Correlations

Correlations were computed between tasks within each age, and cross-age stability was examined for each task. To reduce the number of correlations computed, up to two variables were selected from each task; selected variables were those that did not evidence obvious floor or ceiling effects at either age. For A-not-B, performance on the second post-reversal trial and total number of reversals were selected. For Three Boxes, the total number of reaches was selected. For all imitation tasks, sequence actions were selected. Where necessary, variables were square-root- or log-transformed to reduce skewness or kurtosis; transformations did not alter the pattern of findings. Because we predicted that executive control measures would be positively correlated, and that different tasks using sequence imitation would be positively correlated, one-tailed t -tests were calculated. Most correlations were not statistically significant; only correlations that were significant at the .05 level are discussed here, but the full correlation matrix is available from the first author. At each age, one of the A-not-B performance measures was correlated with modified imitation task performance. At 15 months, A-not-B performance on the second post-reversal trial was positively correlated with the number of sequence actions produced in the Planning task ($r = 0.39$). At 20 months, the number of A-not-B reversals administered was related to the number of sequence actions produced in the presence of distractor props ($r = 0.38$). At 15 months, Three Boxes performance was uncorrelated with A-not-B or any of the imitation measures at both ages. Planning task performance was correlated with immediate imitation ($r = 0.36$ at 15 months; $r = 0.33$ at 20 months), most likely due to shared method variance. At 15 months, the two A-not-B measures were significantly correlated ($r = 0.39$), although at 20 months they were not ($r = 0.25$). Cross-lagged correlations were strikingly low. A child's performance on the A-not-B, Three Boxes, or Planning tasks at 15 months was uninformative as to that child's performance on those same tasks at 20 months, accounting for less than 2% of the variance. The only tasks that showed a significant correlation across time-points were imitation with distractors ($r = 0.36$) and immediate imitation ($r = 0.44$).

Discussion

Developmental changes in executive control were observed across the second year of life, as evidenced by improvements on tasks drawing on two toddler capabilities: searching for hidden objects and imitating sequences of actions. Age-related decreases in perseverative reaching tendencies were most evident on the Three Boxes working memory task: children were less likely at 20 months to reach repeatedly to the same box or location than they had been at 15 months, and as a result they were able to find all hidden rewards in fewer reaches. On the A-not-B, children were better able at 20 months to recover from perseverative reaching to the same location than they had been at 15 months, resulting in completion of more reversals, although other performance measures did not differ across time-points. Children were more able at 20 months than they had been at 15 months to imitate a sequence when they had to select the necessary objects from a broader array of stimuli that included distractor props, and they were also better able to take advantage of a verbal cue provided by the examiner. At 15 months, children were not able to use end-state information to generate a 3-step sequence, but by 20 months this capacity was evident, consistent with previous reports (Bauer et al., 1999).

A common element across executive control tasks is the maintenance of goal-relevant information in mind. In the toddler executive control battery used in the present research, tasks varied in their specific goals and the nature of the information that children had available to facilitate performance. In the reaching tasks, children saw the examiner hide an appealing toy, and in order to retrieve a toy on each trial, children had to update their representation of the hidden toy location across trials based on their own previous behavior (in Three Boxes) or based on trial-specific information (in A-not-B). In the imitation tasks, children saw the examiner utilize novel props to achieve an appealing goal-state, and had to maintain this goal in mind to assist in planning the actions leading up to the goal (in the Planning task), or to select the actions required for a particular goal (in the Distractor task). Improvements across the second year of life may mark the emergence of ability to strategically direct action to achieve goals. Performance at the first assessment (at 15 months) generally reflected an absence of executive control, as mean performance on most dependent measures was in the low range of possible scores, below-chance on A-not-B and baseline-level performance on the Planning task. At 20 months children's overall performance had improved substantially, as children attained chance levels of performance on the second post-reversal trial of A-not-B and showed evidence of planning and ability to overcome interference from distractors. Nevertheless, mean performance was generally midrange relative to possible scores, suggesting that there still is room for further improvement and that the development of executive control could be assessed beyond 20 months using these measures. Most effect sizes for age were small to medium in magnitude, with the exception of sequence imitation with distractors, for which age had a large effect on performance in the initial, uncued phase.

In examining the distributions of each dependent measure, some variables were positively skewed suggesting that at 15 months some children were at floor levels of performance. Neither floor nor ceiling effects were evident at 20 months. Floor performance early in the second year may have reduced the magnitude of the age differences observed in this study. Furthermore, as shown in Table 1, the observed power for some measures was below Cohen's (1988) conventional value of 0.80. Children's performance during the uncued phase of Imitation with Distractors and the Full Model phase of the Planning task resulted in observed power that substantially exceeded 0.80. However, the remaining measures that yielded statistically significant age differences yielded observed power values between 0.66 and 0.79, indicating that if the sample estimates represented the true population values, the sample size used in the present study would have had roughly a two-thirds or better chance

of detecting it. The sample size in the present study was comparable to those used in previous research examining development of reaching and sequence imitation across the second year of life (e.g., Bauer et al., 1999; Bertenthal & Fischer, 1983; Stahl & Pry, 2005; Wiebe & Bauer, 2005); thus, the fact that observed power was relatively modest for some of the tasks, in spite of a reasonable sample size, indicates that the magnitude of developmental change over this period is relatively small.

Power also was a consideration in analyses of correlations between measures. Given the sample size of 30 children, this study had 80% power to detect a correlation of .44, but most observed correlations were less than this value, indicating that the patterns must be interpreted with caution. Nevertheless, there were hints that several tasks may have required the same or related abilities. A-not-B performance was correlated with Planning task performance at 15 months, and with Imitation with Distractors at 20 months. Both of these tasks require children to resist interference generated by task contingencies. In the A-not-B task, to reach correctly on reversal trials, children must maintain an active representation of the current location of the hidden object and resist proactive interference from the opposite, previously-correct location. Even at 20 months performance on the first post-reversal trial was below chance. Not until the second post-reversal trial did performance reach chance level in the group as a whole. On sequence imitation with distractors, interference is created through the addition of distractor objects to the array of test stimuli. Children must remember the three actions of the to-be-imitated sequence (and their order), and may need to inhibit competing goals and actions activated by the distractor props. Although these findings must be viewed as preliminary because of the relatively small sample size, they are consistent with the adult literature, as Friedman and Miyake (2004) found that tasks requiring inhibition of prepotent responses and resistance to interference from distractors loaded on the same latent factor, suggesting that they draw on the same underlying dimension of executive control. Three Boxes performance did not correlate with the remaining executive control tasks.

The tasks included in the test battery revealed change in executive control performance across the second year, and manipulations to reaching measures appear to have been successful in capturing developmental differences not apparent in previous longitudinal work (Diamond et al., 1997). However, there was little stability in performance on individual tasks from 15 to 20 months. Because the second year is a time of rapid transition, children may differ in their rates of executive control growth, which could decrease the magnitude of correlations across age. To address this possibility, a future study should incorporate more frequent assessment to identify periods of change. Furthermore, a substantial concern in the assessment of young children's cognitive performance is reliability of assessment (Espy, Bull, Kaiser, Banet, & Martin, 2008). It is likely that children's performance on the tasks also was influenced by factors other than the specific constructs they were designed to measure, an issue universal to executive control measures (Miyake et al., 2000). For example, children's Three Boxes performance was largely accounted for by the degree to which children tended to respond repeatedly to the same location or box, indicating that children may have been responding according to idiosyncratic strategies rather than strategically utilizing working memory. Similarly, at 15 months, children's Planning Task performance was equivalent to baseline, and so may be less reflective of executive control, whereas at 20 months children's performance may reflect a higher degree of "true score" variability. As such, some tasks may be better indices of executive control at specific points within the second year. Further work is necessary to explicitly address this possibility, through inclusion of larger samples would allow the use of statistical techniques such as confirmatory factor analysis, that permit the examination of the structure of executive control across age to see if the contribution of latent executive control

to task performance indicators changes across early development (e.g., Wiebe, Espy, & Charak, 2008).

There is substantial interest in understanding the early development of executive control, particularly in the case of children at risk for developing disruptive behavior disorders (Nigg & Casey, 2005). The present study contributes to this literature by presenting preliminary longitudinal comparisons on a battery of executive control tasks sensitive to age differences across the second year of life. A critical next step will be to clarify the relations between executive control measures within the second year of life, in a larger sample with power to detect smaller correlations between measures, and to identify the nature of change in executive control in the second year through more frequent time sampling. The availability of a broader range of executive control tasks will permit work examining interrelations between early cognitive control, other facets of self-regulation (e.g., control of negative emotions, ability to delay gratification), and clinical symptomatology related to dysregulation in at-risk populations.

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Appendix

Action Sequences used in Imitation Tasks

Task		Sequence Description
Age	Label	Steps
Immediate Imitation		
15 months	Frog Rattle	(1) Place block inside frog-shaped cup; (2) Cover cup to enclose block; (3) Shake cup to produce rattling sound.
	Merry-go-round	(1) Close hinged disc with attached horses; (2) Place disc on base; (3) Spin disc
	Popper	(1) Pull handle to reveal ball opening; (2) Place ball in opening; (3) Push handle so that ball pops out bottom chute
	Sled ride	(1) Place ramp on block base to form incline; (2) Attach wheels to sled with Velcro; (3) Push sled down ramp
20 months	Clowns	(1) Remove barrier from base; (2) Assemble clown figure; (3) Place clown on base; (4) Turn handle to spin clown
	Dumptruck	(1) Put on dumptruck bottom piece; (2) Attach dumper; (3) Place blocks in dumper; (4) Tip dumper to dump blocks
	Jumper	(1) Assemble base; (2) Place globe/ball apparatus on base; (3) Push ball to release from globe; (4) Press handle to make ball jump
	Silly worms	(1) Lift covering piece; (2) Pull trap door; (3) Insert handle; (4) Turn handle to spin “worms”
	Tools	(1) Open sides of base; (2) Place top piece with pegs on base; (3) Assemble the hammer; (4) Use hammer to pound pegs
Imitation with Distractors	Dancing Bear	(1) Place stick in circular base; (2) Attach bear to stick with Velcro; (3) Pull string to make the bear dance
	Flowerpot	(1) Place center piece in ring; (2) Place ring assembly in flowerpot; (3) “Plant” flowers in pot
	Glowball	(1) Place ring on wheeled base; (2) Place metallic ball on ring; (3) Move wheeled base back and forth

Task		Sequence Description
Age	Label	Steps
Planning Task	Gong	(1) Place crosspiece on gong base; (2) Hang bell from crosspiece; (3) Strike bell with mallet
	Hang Glider	(1) Attach doll to stick; (2) Remove top cover from ramp; (3) Slide doll/stick down ramp
	Hopper	(1) Place connecting rod in base; (2) Place top cone on connecting rod; (3) Pull handle to cone "hop"
	Motion Drum	(1) Place Velcro ring on spinning base; (2) Place diagonally-striped cylinder on ring; (3) Turn the cylinder
	Paddle Rattle	(1) Place plastic piece on flat base; (2) Place over base; (3) Shake rattle
	Squid Jump	(1) Place board on triangular base to make "seesaw"; (2) Place toy squid on bottom end; (3) Strike raised end to make squid "jump"
	Wheel	(1) Lift hinged side of base; (2) Place wheel on base; (3) Spin the wheel
	Windmill	(1) Attach spinner to connecting piece; (2) Insert connecting piece into windmill base; (3) Spin the windmill
	Drum	(1) Place paddle into notched edge of round base; (2) Attach cover to base; (3) Strike paddle to "play drum"
	Fruit chute	(1) Open hinged ramp; (2) Prop ramp on notched base; (3) Roll toy fruit down ramp
	Horseride	(1) Place stick in base; (2) Put horse onto stick; (3) Pull handle to move horse back and forth
	Top	(1) Put circular ring with bears onto base; (2) Place cover with plunger over bear; (3) Press plunger to spin bears

Note: Comprehensive descriptions, including photographs, for most of the sequences used in this study have been published elsewhere (see Bauer et al., 1999, 2000; Wiebe & Bauer, 2005).

Table 1

Descriptive statistics for task performance, by age.

Task Dependent measure	Range of Possible Scores	Age		Observed Power
		15 months	20 months	
		M (SD)	M (SD)	
A-not-B with invisible displacement:				
Proportion correct (first post-reversal trial)	0 – 1	0.24 (0.38)	0.30 (0.36)	0.10
Proportion correct (second post-reversal trial)	0 – 1	0.22 (0.33)	0.40 (0.36)	0.48
Total reversals administered	0 – 4	1.57 (0.94)	2.23 (1.14)	0.66
Trials to criterion	≥ 2	3.56 (2.06)	4.25 (2.99)	0.15
Three Boxes:				
Total reaches	≥ 3	5.76 (1.70)	4.72 (1.03)	0.76
Maximum consecutive reaches to same spatial location	≥ 1	3.14 (1.65)	2.37 (1.02)	0.70
Maximum consecutive reaches to same box	≥ 1	2.36 (1.17)	1.75 (0.73)	0.67
Immediate imitation:				
Proportion of sequence actions (baseline)	0 – 1	0.27 (0.21)	0.33 (0.18)	0.21
Proportion of correctly-ordered pairs (baseline)	0 – 1	0.12 (0.18)	0.11 (0.13)	0.05
Proportion of sequence actions (imitation)	0 – 1	0.68 (0.25)	0.80 (0.18)	0.77
Proportion of correctly-ordered pairs (imitation)	0 – 1	0.45 (0.27)	0.54 (0.19)	0.38
Imitation with Distractors:				
Sequence actions (uncued phase)	0 – 3	0.80 (0.71)	1.83 (0.81)	> 0.99
Correctly-ordered pairs (uncued phase)	0 – 2	0.13 (0.30)	0.80 (0.66)	> 0.99
Sequence actions (after verbal cue) ^a	0 – 3	0.13 (0.35)	0.40 (0.46)	0.76
Correctly-ordered pairs (after verbal cue) ^a	0 – 2	0.07 (0.22)	0.22 (0.31)	0.66
Sequence actions (after distractors removed) ^a	0 – 3	0.52 (0.58)	0.40 (0.55)	0.14
Correctly-ordered pairs (after distractors removed) ^a	0 – 2	0.23 (0.40)	0.15 (0.33)	0.13
Planning task:				
Sequence actions (baseline)	0 – 3	0.97 (0.51)	1.02 (0.58)	0.06
Correctly-ordered pairs (baseline)	0 – 2	0.13 (0.26)	0.20 (0.31)	0.16
Sequence actions (end-state)	0 – 3	1.23 (0.73)	1.75 (0.79)	0.79

Task Dependent measure	Range of Possible Scores		Age		Observed Power
			15 months	20 months	
			M (SD)	M (SD)	
Correctly-ordered pairs (end-state)	0 – 2		0.28 (0.39)	0.53 (0.45)	0.60
Sequence actions (full sequence)	0 – 3		1.87 (0.88)	2.35 (0.72)	0.93
Correctly-ordered pairs (full sequence)	0 – 2		0.83 (0.67)	1.25 (0.69)	0.95

^aFor Imitation with Distractors, children received credit only once for the production of a particular sequence action or correctly-ordered pair, so the range of possible scores at later testing phases was inversely related to a child's performance at earlier phases.

Table 2
Summary of regression analyses for Three Boxes performance and indices of perseveration at 15 and 20 months.

Variable	15 months (<i>n</i> = 29)			20 months (<i>n</i> = 30)		
	<i>B</i>	<i>SE (B)</i>	<i>β</i>	<i>B</i>	<i>SE (B)</i>	<i>B</i>
Intercept	1.52**	0.43		1.71***	0.36	
Maximum consecutive reaches to same spatial location	0.73***	0.09	0.71	0.53***	0.10	0.52
Maximum consecutive reaches to same box	0.82***	0.12	0.56	1.00***	0.14	0.71
<i>R</i> ²				0.81	0.74	
<i>F</i>				55.83***	38.12***	

**
p ≤ .005

p ≤ .0001